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Brooks, John

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Fire Control for British Dreadnoughts: Choices of Technology and Supply

John Brooks

Department of War Studies

King's College, London

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ABSTRACT

By choosing the Dreyer Fire Control Tables, the Admiralty is widely considered to have rejected Pollen's Argo system for an inferior plagiarism which contributed to Beatty's defeat at Jutland. This thesis begins with a summary and critique of Professor Jon Sumida's influential work and argues for a re-examination of his conclusions. It then sets out the general principles of long range naval gunnery: the different types of plotting: and the limited accuracy of available target data. Next, it considers the progress in gunnery made after 1900 and how the necessary instruments were invented, developed and supplied. This establishes a context for Pollen's relationships with the Admiralty, which are recounted after setting out the function and status of each component of his evolving system. The development and operation of the Dreyer Tables are then discussed. After an outline of German fire control, the Run to the South and the demands on the opposing gunnery systems are described using the surviving gunnery data; finally, the lessons drawn by the Royal Navy at the War's end, as embodied in a new generation of Admiralty Fire Control Tables, are reviewed. The conclusions are threefold.

Influences. Both the Dreyer and Pollen clocks incorporated principles first proposed for the other or anticipated in Service gear, yet their detailed designs were quite different. The charges of plagiarism are unjustified and inappropriate.

Choices. When his monopoly ended, Pollen had no clear technical lead in clocks or plotting. His own obduracy threw away the opportunity to become a normal commercial supplier. The Admiralty's decision was the outcome of reasoned technical and commercial choices.

Consequences. The conditions of the Run to the South did not favour *Queen Mary's* Argo clock. Beatty's defeat was due not to his fire control but to a badly-handled approach and subsequent confusion in his line.

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INTRODUCTION

The first encounter between heavy ships at Jutland is now known as the Run to the South. It began as an engagement between five German and six British battlecruisers, though, later, Hipper's squadron was also under long-range fire from four *Queen Elizabeth* class battleships. Yet, despite a superiority in ships and weight of fire, Beatty lost both the *Indefatigable* and *Queen Mary* to catastrophic magazine explosions. This defeat (for no other description is appropriate) can be partly explained by the inferior armour protection and the exposed and inflammable propellant charges of the British ships, and the effective armour-piercing German shell.[1] However, these factors were only important because the Germans gained a decisive gunnery superiority, Beatty's battlecruisers making no more than 11 hits compared with up to 42 received.[2]

There is today a broad consensus on the main cause of this failure of British gunnery and how it had arisen.

> The British undoubtedly paid a severe penalty for the failure to adopt before the war the system devised by Arthur Hungerford Pollen....The Pollen system would undoubtedly have enabled the British battlecruisers to hit before they were hit in return, thus offsetting their deficiencies in armour protection and unsuitable propellant.[3]

> Instead of the effective Argo Clock, [Frederic] Dreyer had persuaded the Admiralty to adopt a plagiarized and inferior instrument co-designed by himself and...Keith Elphinstone.[4]

> In taking observed and estimated data, and adding both manual delays and mechanical errors, Dreyer's system deprived the guns of the responsiveness of direct observation,

[1] Arthur Marder, *From the Dreadnought to Scapa Flow, Volume III* (Oxford, 1978) pp.204-15. N J M Campbell, *Jutland, an analysis of the fighting* (London, 1986) pp.369-87. Stephen Roskill, *Admiral of the Fleet Earl Beatty* (New York, 1981) p.130.
[2] Campbell, *Analysis* (*op. cit.*) pp.78 and 94. Campbell's tally of hits is assessed in Chapter 6.
[3] Paul H Halpern, *A Naval History of World War I* (London, 1994), p.328.
[4] Eric Grove, *Fleet to Fleet Encounters* (London, 1991) p.72.

> and yet failed to produce accurate results in conditions of fast-changing rates of change of range and bearing.[5]

> What the effects on Jutland might have been if most of the British heavy ships had been fitted with the Argo Clock is of course largely conjectural; but its obvious superiority to the system actually installed, together with the fact that the *Queen Mary*, which did the best shooting of Beatty's ships, was fitted with the Argo Clock Mark IV leaves one in little doubt that they would have been substantial.[6]

All these distinguished naval historians base their conclusions on the research and publications of Professor Jon Tetsuro Sumida. After his first paper in 1979,[7] Sumida edited the papers of Arthur Pollen (published in 1984)[8] and, in 1989, brought out *In Defence of Naval Supremacy*. This book, now established as a classic of naval history, has three principal themes. Firstly, it elucidates the financial restraints at the start of the dreadnought era, and how they were overcome to pay for the construction of the Grand Fleet. Secondly, it establishes Fisher's preference for battlecruisers over battleships, and suggests that he was influenced by developments in fire control which promised to make fire effective at long range. And, thirdly, it describes Arthur Pollen's campaign from 1901 to 1913 to persuade the Royal Navy to adopt his fire control system: and its eventual rejection in favour of the Dreyer Fire Control Tables.

As its title implies, the main purpose of the present thesis is to re-examine the Admiralty's choice, finalised in 1913, between the rival fire control technologies and their respective suppliers, the Argo Company and Elliott Brothers: but it will also consider the extent to which Dreyer and Elliotts were truly culpable of plagiarism, and the actual consequences of that choice in the naval engagements of the Great War, especially the Run to the South. Any attempt to argue for a reconsideration must begin by attempting to summarise Sumida's own conclusions on these matters, although this is no easy task, given his detailed and scholarly exposition. To begin with the question of plagiarism:

> ...a tribunal of the Royal Commission on Awards to Inventors...ordered that Pollen be paid the sum of £30,000 compensation for the plagiarization [*sic*] of the Argo Clock that had occurred in 1911, the fact of which had been exposed in hearings that had taken place in August 1925.

[5] Andrew Gordon, *The Rules of the Game* (London, 1996) p.12.

[6] Roskill, *Beatty* (*op. cit.*) p.192.

[7] Jon Sumida, 'British Capital Ship Design and Fire Control in the Dreadnought Era: Sir John Fisher, Arthur Hungerford Pollen, and the Battle Cruiser', *Journal of Modern History*, 51 (June 1979) pp.205-30. This was followed by Anthony Pollen, *The Great Gunnery Scandal* (London, 1980), a loyal defence of Pollen by his son.

[8] A balanced review of the Dreyer-Pollen controversy by Frederic Dreyer's son, Admiral Sir Desmond Dreyer, did not influence subsequent publications: 'Early Developments in Naval Fire Control', *The Naval Review*, July 1986, pp.238-41.

After the many problems experienced during the *Natal* trials in 1910, 'Pollen...had decided to redesign the plotter and clock from start to finish in order to produce instruments which could not be faulted on technical grounds'.[9] Work began on the clock in early 1911. At that time, Elliott Brothers were already manufacturing the first instrument which 'combined Dreyer's rate plotting elements with a dumaresq and Vicker's Clock'. Shortly thereafter:

> ...Keith Elphinstone, an engineer at Elliott Brothers...began design work on an improved clock...Henley...Moore's assistant[10] had previously kept Dreyer fully informed of confidential matters relating to the Argo Company, and by July at the latest, both Elphinstone and Dreyer were familiar with the mechanical details of the [new] Argo Clock. Elphinstone, in addition, was a frequent visitor to the Cooke's works at York, and in October 1911 with Henley examined both the clock, which was then under construction, and all the drawings.
>
> The new model Dreyer-Elphinstone Clock was at best an imperfect development of the dumaresq - Vickers Clock combination.....the dumaresq that was part of the Dreyer gear...calculate[d] change of range of [*sic*] bearing rates that were then transmitted automatically via a mechanical linkage to the clock. The basic mechanism of the clock consisted of two disc-roller units, one of which generated ranges and the other bearings....The generated bearings...controlled the bearing setting of the dumaresq, which in addition could be altered by the action of a gyro compass whenever the firing ship made a turn.
>
> The clock mechanism bore an unmistakable resemblance to the disc-ball-roller arrangement of the Argo clock, which in the light of the proceedings described above, was probably not coincidental - this, in any case, was the judgement of a government tribunal that met in 1925. The plagiarism of the Argo instrument, if such it was, however, was incomplete and in operation thus far less efficient.[11]

This is a serious indictment, but it also raises questions, both personal and technical. Pollen had viewed Dreyer as a rival ever since the *Ariadne* trials of early 1908; why, then, would he have allowed Elphinstone, the designer of the competing system based on Dreyer's ideas, to see the new Argo clock and any, let alone all, of the drawings? And what, exactly, had been plagiarised? A dumaresq was part of the Dreyer gear; but the Argo clock was also 'equipped with a virtual-course-and-speed calculating mechanism - in essence a dumaresq'. The Dumaresq, moreover, was an instrument which had been invented in 1902 and was in service by 1906: so clearly this was not plagiarised from Argo. As for the clocks, the Argo contained three variable-speed drives of the disc-ball-roller (actually two rollers) pattern: while the Dreyer/Elphinstone apparently

[9] Jon Sumida, *In Defence of Naval Supremacy. Finance, Technology and British Naval Policy 1889-1914* (London, 1989) pp.202-3 and 316.
[10] Henley was the assistant to the Director of Naval Ordnance, Rear-Admiral Moore, with responsibility for fire control: *ibid.* p.213.
[11] *ibid.* p.219.

used two, more conventional disc-and-roller drives, in which case the shape and function of the rollers in the two types of drive were entirely different.

> ....the absence of adequate provision to reduce friction during the translation of the roller along the diameter of the disc probably resulted in slippage that introduced errors in the generation of ranges and bearings....the cast iron discs of the Dreyer/Elphinstone Clock were undoubtedly more susceptible to wear than the hardened steel discs of the Argo device....[12]

The Argo mechanism was evidently better: but since neither the numbers nor the designs of the drives were the same, where lay the 'unmistakable resemblance'? A study of the functional and mechanical details of the two designs will be necessary in order to determine how closely the Dreyer/Elphinstone really resembled the Argo: and, indeed, whether Argo owed any debts to Service antecedents.

Sumida is in no doubt that the Dreyer Tables were inferior to the Argo system.

> Dreyer's method could not have produced satisfactory results...if forced to contend with the high and changing change of range and bearing rates, and interruptions in visibility that Pollen and others believed were likely to occur in battle. Under such conditions, the inability of the time-and-range and time-and-bearing plots to contend with the changing rates would mean that the dumaresq would give an inaccurate indication of the target speed[13], the occasional obscuring of the target would cut off the supply of bearings required to reset the dumaresq, while continuous changes in the range rate could not be represented accurately by the Vickers clock, whose drive speeds...could only be altered in discrete steps.[14]

In fact, Sumida now acknowledges that the Vickers clock contained a variable speed drive which could be adjusted continuously for rate, but he still insists that:

> Changes in the indication of the rate by the dumaresq had to be transferred manually to the Vickers clock, and because such transfers could not be carried out continuously, continuous change in the range rate was imperfectly represented by the clock....[15]

The Dreyer Tables in Beatty's ships at Jutland are characterised thus.

> ...*Indefatigable* and *New Zealand* were fitted with the Dreyer Table Mark I whose dumaresq/Vickers clock arrangement was incapable of taking account of a changing change of range rate with any degree of precision....*Lion* and *Princess Royal*...were fitted with the Dreyer Table Mark III...*Tiger*...with the...Mark IV, both of whose dumaresq/ Dreyer-Elphinstone Clock combinations were probably much superior...but still not entirely satisfactory. Only the *Queen Mary* was equipped with the Dreyer Table Mark II,

[12] *ibid.* pp. 74, 101, 169-70, 211-3, 219 and Plate 5.
[13] A 'cross-cut' of the rates (slopes) from the range and bearing plots was used in setting the Dumaresq's target course as well as speed: Jon Sumida (ed.) *The Pollen Papers* (London, 1984) pp. 371-3.
[14] *IDNS* (*op. cit.*) pp.217-8.
[15] Jon Sumida, 'The Quest for Reach: the Development of Long Range Gunnery in the Royal Navy, 1901-1912' in Stephen D Chiabotti (ed.) *Tooling for War: Military Transformation in the Industrial Age* (Chicago, 1996) pp.60 and 87; the opportunity to see a proof copy of this paper is gratefully acknowledged.

> which incorporated an Argo Clock Mark IV...designed to deal with high and changing change of range rates, and interruptions in the observations of the target...[16]

However, some of these descriptions are inconsistent with those given elsewhere. Firstly, the imperfections due to manual rate transfer were apparently confined to the prototype Dreyer Table under construction in early 1911. In the Dreyer Table Mark I, the 'dumaresq and Vickers Clock were connected by a mechanical linkage which automatically set the rate of the former to match the indications of rate on the latter instrument'; in the Dreyer/Elphinstone clock of the Dreyer Table Mark III, the rates were also transferred automatically, while the later Mark IV had a 'new model "electric dumaresq" ' which, although not described, does not sound any less automatic than its mechanical predecessors. Secondly, the Argo Clock could not always predict accurately when target observations were interrupted.

> ...so long as the firing ship and target steamed on straight courses and constant speeds, the clock would...generate ranges and bearings without the need for further bearing corrections. If the firing ship turned the automatic setting of calculated bearings was superseded by hand set bearings obtained by observation.

And, thirdly, while, in 1913, the Argo Clock Mark V (which was completed too late to be considered by the Royal Navy) had been provided with a gyrocompass connection 'that corrected the bearing setting of the clock when the firing ship was turning', this feature had already appeared in the Dreyer/Elphinstone clock of 1911; Beatty himself later assured Pollen that the Dreyer Table was helm-free, although this view is dismissed by Sumida as 'mistaken'.[17]

He also criticises the mechanical design of the Dreyer/Elphinstone clock: but accepts that only the Dreyer Table allowed the predicted and observed ranges to be compared directly.

> ...to compensate for inaccuracies in the speed and course settings of the dumaresq that were the result of rate plotting - if not for the inherent defective operation of the clock mechanism, which may not have been appreciated - the Dreyer-Elphinstone Clock was made to drive a marking pencil that plotted generated ranges alongside the plot of observed ranges. By this means, ranges...could be quickly compared...and the clock settings adjusted whenever the plots diverged. This ingenious method of "feed-back" correction did much to enable the various production marks of the Dreyer Table...to produce acceptable results under the unrealistic and easy conditions of Battle Practice, and this was a major factor in the rejection of the far superior Argo system.[18]

[16] *IDNS*, p.300.
[17] *ibid.* pp.213, 219, 247, 251, 283-4 and 306.
[18] *ibid.* pp.220.

It is clear that a fuller understanding is needed of the functional and design characteristics of the rival systems as they evolved through a succession of models, including the Argo true-course plotter of 1913. Only then can a judgement be reached on whether the Admiralty did in fact reject a far superior system.

However, whatever the technical issues, Sumida's account suggests that many decisions were motivated mainly by opposition to Pollen and his ideas from the Naval Ordnance Department. Even in 1905, when Pollen requested funds to develop a gyroscope for correcting bearing observations, 'the Ordnance Department insisted that yaw would not be a significant factor, and categorically refused to provide funds for the project'. Nonethless, at this time Pollen established a good relationship with the new Director of Naval Ordnance, Jellicoe, who initiated the negotiations for the contract under which Pollen expected to be paid £100,000 for his system. In August 1907, Jellicoe was replaced as DNO by Reginald Bacon, who was:

> ...opposed to the employment of complicated machinery for fire control purposes....There is good reason to believe, therefore, that Bacon was determined from the start to prevent the adoption of Pollen's mechanised system of fire control.
> Bacon's objectives were undoubtedly also those of Lieutenant Frederic C. Dreyer...

Dreyer, already a member of the DNO's department, had previously served as Gunnery Staff Officer to Sir Arthur Wilson in the Channel Fleet: and Sumida proposes that:

> It was while serving under Wilson that Dreyer's rivalry with Pollen as an inventor of fire control instruments had begun.

Dreyer was now about to participate in the forthcoming trials of Pollen's new equipment aboard *Ariadne*.

> The selection of Admiral...Wilson to umpire the official trials insured that Dreyer's desire to play a major role in the blocking of Pollen would be fulfilled...Bacon assigned Dreyer to be [Wilson's] assistant. Wilson's nomination undoubtedly originated with Bacon, who must have been aware of his dependence upon Dreyer for advice on all gunnery matters.[19]

Wilson soon became strongly opposed to the terms of Pollen's contract and conducted the trials as a competition with a manual plotting scheme concocted by himself and Dreyer. He declared that the results showed that his own method was 'vastly superior' and his report recommended the rejection of the Pollen system. In March 1908, the Admiralty acted on this advice, though not before some dubious dealings with Pollen. Sumida suggests that, unlike in 1905, Fisher and the Controller, Jackson, had failed to support

[19] *ibid.* pp.84, 99, 121 and 123.

Pollen because they had 'been persuaded by Dreyer that the service had produced a cheap and effective alternative': and, furthermore, that, since Wilson's report was most difficult to follow:

> Fisher and Jackson had little technical understanding of the latest advances in gunnery, which meant that they were incapable of exposing subtle prevarication when it came to the arcana of fire control.[20]

Although Pollen did not receive his £100,000, a further payment of £11,500 provided him with 'the working capital necessary for me to carry on'. Despite this continuing financial support, Bacon is said to have maintained his 'opposition to mechanized methods of gunnery [which] included mechanized gunlaying as well as sightsetting' and that, in the Spring of 1909, 'Scott and Pollen...found themselves sharing the status of gunnery outcasts'. Yet, between April and June, the Admiralty negotiated and placed an new order with Pollen's recently announced Argo Company for a set of instruments for trial in *Natal*: and also asked for a tender for a production order. Sumida's account says that the delay in placing the order was due to 'Bacon's obstruction' and that 'the Ordnance Department retained both the means and the will to prevent a fair trial'. Furthermore:

> The new plotting table had been designed to allow plotting...while the ship...was turning....The Ordnance Department, however, apparently did not believe that the capacity to plot while turning justified the increase in mechanical complexity, and thus the plotting table as supplied did not incorporate [this] feature.

Yet Pollen would soon see 'a dramatic improvement in his relations with his leading opponent' when, on 8 July, ' "the D.N.O. went arm in arm with Pollen to [the Linotype factory in] Manchester and came back much impressed. He is now sincerely anxious for the experiments to succeed" '. By November, Bacon was suggesting that Argo and the Admiralty should 'come to a comprehensive agreement with regard to secrecy and the purchase of Pollen's system'.[21]

At the close of 1909, Bacon was replaced as DNO by Captain Archibald Moore, while Wilson took over from Fisher as First Sea Lord.

> Moore was critical of the mechanical reliability of the gyro-stabilized range-finder mounting...and doubtful that plotting was of any value. The Contracts Department... believed that Pollen's profit margins were excessive. These unfavorable assessments were consistent with, if not in part, prompted by, the views of Admiral Wilson...who was adamantly opposed to any monopoly agreement.

[20] *ibid.* pp.124-36.
[21] *ibid.* pp.137-8, 153-4, 164-6, 170-1 and 174.

Even though, subsequently, 'Pollen appears to have been told that Wilson's opinions were not the obstacle that he supposed', Sumida states that 'Wilson remained adamantly opposed to any purchase that involved secrecy terms'.[22] Yet the final contract, accepted on 29 April 1910, preserved monopoly and secrecy until the end of 1912, ordered 45 mountings and indicators at £1,350 per set and included provision for an advance payment of £15,000. These conditions are described as 'unfavourable terms of purchase for only a portion of his [Pollen's] fire control system, which provided a margin of profit that was too small to enable the Argo Company to carry on experimental work on the other instruments'. During the *Natal* trials in July: 'The Argo instruments suffered from numerous mechanical and electrical failures', not excluding even the rangefinder mounting, while the plotter proved to be 'faulty in design'. Yet it is suggested that 'Moore's rejection of the Argo plotter may in addition have been motivated by his preference for an alternative plotting system that had just been brought to his attention'. This was dual rate plotting, incorporated in the table patented by Dreyer in September 1910.[23]

By the end of 1911, the prototype Dreyer Table had been tried aboard *Prince of Wales* (in which Dreyer was Flag Commander to Jellicoe), while design of the new Dreyer Table Mark III was proceeding at Elliott Brothers. At the Argo Company, the Argo Clock Mark IV was nearing completion, while the 'delayed design work on the improved helm-free/true-course plotter' was probably only just beginning.

> The obstruction of Admiral A.K. Wilson had played an important role in the disruption of the development of the Pollen system [but] he was forced to resign...in November 1911. Moore, on the other hand, kept his place as Director of Naval Ordnance, and although his private relations with Pollen were friendly, he remained nevertheless a determined opponent of true-course plotting and secrecy agreements with the Argo Company.

Further on in his book, Sumida describes Moore as 'an inveterate opponent of Pollen's approach to fire control', yet:

> On 10 April 1912, Moore...informed Pollen that he would recommend the adoption of the [Argo] clock for the five [*sic*] battleships of the King George V class pending the outcome of sea trials and an agreement over prices.

However, Pollen refused to quote for this small number: asked for large orders or an immediate release from secrecy: and was unwilling to consider maintenance of secrecy on

[22] *ibid.* pp.196-8 and 269; the only source given for Wilson's continuing hostility is a draft but unsent letter written by Pollen in September 1912.
[23] *ibid.* pp.201-2, 205 and 218.

only part of the Argo system. There then followed the obscure episode in which Pollen was officially censured for imputations made against Dreyer in an earlier letter. Sumida believes that:

> ...Moore was determined to block the advance of the Argo Company [and] that [their] refusal to consider monopoly on an *à la carte* basis...in his mind might have justified underhand action on his part.

Whether or not this episode was responsible for 'the development of a personal animus against Pollen on the Board', on 13 August Moore (who was now Controller) advised his colleagues:

> ...everything that the Argo Company professes to achieve with its instruments, can be equally well performed by the Dreyer instruments....I do not see any reason for continuing the privileged position of this inventor...it is full time that he was placed in the same position as all other inventors....

However, despite taking Moore's advice to end the secrecy agreement, the Admiralty still accepted Argo's tender for five (later increased to six) clocks.[24]

The trials of the new clock, held aboard *Orion* in November, were a success but, despite further negotiations, 'the Admiralty...concluded that they could make no offer which the Argo Company could accept'. In January 1913, Churchill was sent extracts from letters of support which Pollen had received from supporters in the Service, which were judged to be "grossly improper and offensive". In the next six months, relationships between Argo and the Admiralty continued to deteriorate, exacerbated by a dispute over rate-setting dials on the Argo Clock which, according to the new DNO, Captain F C T Tudor, revealed the Service system of rate control.

> Tudor appears to have demonstrated a hostility to the Argo Company that was at least as great as Moore's....Tudor's views carried the day and his scheme of obstructing the foreign sale of the Argo Clock officially adopted.

By June 1913, the rejection of the Argo system was public knowledge and questions were about to be asked in Parliament. By late July, the Admiralty had prohibited all communication with Argo and, in September, the company began its sales campaign abroad.[25]

Sumida proposes two other influences on the Admiralty's decisions in 1912 and 1913. The first was the introduction of 'rangefinder control', in which the clock range was continually corrected by the mean range-finder range of the moment obtained from a

[24] *ibid.* pp.215, 219-25, 235, 262 and 276-7.
[25] *ibid.* pp.231, 234-7 and 241-7.

Dreyer range plot of several rangefinders. The second was their assessment that 'the German navy would seek a short-range engagement' at ranges 'much less than 10,000 yards...by closing rapidly'. Sumida returns to this second theme in his more recent article 'The Quest for Reach'. He acknowledges that, in 1910, Pollen argued:

> that the conditions of short-range gunnery favored the adoption of his mechanized system because it was much more capable than any manual system of plotting range and range generation for dealing with variation in the change-of-range rate.

but nevertheless concludes that:

> In 1912...the Admiralty rejected the Pollen system for Dreyer's cheaper but less capable alternative on the grounds that state-of-the-art sight-setting equipment would not be required to deliver overwhelming firepower in the first few minutes of the close-range naval battle that it believed would be fought against the Germans....This ended the quest for reach that had been initiated in 1901.[26]

In Defence of Naval Supremacy provides few explanations for the actions and choices attributed to the responsible Admiralty officials. Why did the Naval Ordnance Department reject yaw-correction for the *Jupiter* gear and helm-free plotting for the first *Natal* table? The decision of March 1908 not to purchase in quantities the AC rangefinder mounting and plotter is explained by Bacon's rooted objection to complex instruments and Wilson's hostile reaction to the terms of Pollen's contract; yet were they not also influenced by being in the middle of a period of severe restraint on naval expenditure?[27] Why, before he left office, did Bacon suddenly change from obstructing to supporting both trials and a production agreement? The contract for the supply of 45 rangefinder mountings appears to confirm that Wilson, as First Sea Lord, was not adamantly opposed to a monopoly agreement with Pollen; consequently, it is not clear why Wilson is accused of obstructing and disrupting the development of Pollen's system until his resignation. Moore is shown to have been sceptical, when he took office, about the reliability of the mounting and the value of the true course plotter: rightly, as the trials in *Natal* were to show. Yet no clear evidence is provided that he then became Pollen's inveterate opponent; it was Moore who insisted on the purchase of five Argo clocks for the latest class of battleship. His opposition to the continuation of secrecy and monopoly only hardened after three months of fruitless negotiation, while his own words indicate that, in the second half of 1912 he was opposed only to secrecy, not to Argo remaining a supplier, though on more usual terms. The final breach did not come for almost another year.

[26] *ibid.* pp.250-3. 'Quest for Reach' (*op. cit.*) pp.71 and 80.
[27] *IDNS*, p.113 and Tables 6 and 8.

Tudor, Moore's successor, is said to have used the question of secrecy as a pretext for obstructing Argo's foreign sales: but Sumida's account does not hide that the breakdown was also due to the provocative actions of Pollen and his associates.

These questions and doubts cannot be addressed while the Argo affair is interpreted principally from Pollen's viewpoint. Direct evidence must be sought of how and why the Admiralty made the choices which led, eventually, to the break with Argo. Moore, and Wilson too,[28] evidently considered that Pollen's treatment as an inventor was exceptionally privileged; how, then were inventions (from within and outside the Navy) normally developed into serviceable instruments: and what were the roles played by Admiralty and industry in this process? A study of the evolution of the Royal Navy's complete fire control system, of which clocks and plotters were but a part, will, it is hoped, provide a technical and commercial context against which the Admiralty's decisions can be assessed.

In analysing the consequences of their choice for the battlecruisers during the Run to the South, Sumida concludes that:

> ...change of range rates must...have been a critical factor...the convergence and divergence of the opposing sides resulted in change of range rates that were high - between 4:00 and 4:10 the average change of range per minute was 350 yards - and changing....
> ...the rate-plotting mechanisms of the Dreyer tables were incapable of producing estimates of the...rates...when the...rates were high and changing rapidly. In addition, the manual process of plotting and meaning ranges was so slow that corrections to the clock...probably lagged significantly behind the actual instantaneous range.

Similarly, in the second phase of the engagement:

> converging paths...between 4:10 and 4:19 gave an average change of range of nearly 600 yards per minute. Between 4:19 and 4:28 both sides altered course several times and the Germans reduced their speed. The change of range under these circumstances was unquestionably high and changing. At 4:26, the *Queen Mary* was sunk by two hits amidships ....
> ...The change in the change of range rate factor was again probably critical....

In this phase, the 5th Battle Squadron was also firing but for them:

> ...speeds were nearly equal and the angle of convergence moderate, the change of range rate was well under 200 yards per minute and probably nearly constant.[29]

Yet they were required to contend with the same changes of German courses as the battlecruisers, while, after 4.19, they were on much the same course as Beatty's ships.[30]

[28] *ibid.* p.125.
[29] *ibid.* pp.300-3.
[30] *FDSF III* (*op. cit.*) Chart 5.

Also, Sumida's description of the German fire control system states that ranges from the stereoscopic rangefinders were meaned by a calculating machine, not plotted: that they had 'nothing better than the German equivalent of the dumaresq...and Vickers clock'; and that the clock ranges were not even transmitted to the guns; he does not explain why:

> The absence of a [range] plot...may have enabled the German fire control team to respond more quickly, if not precisely, to changes in the range rate.[31]

Once again, many questions are raised. What were the courses and speeds, and hence ranges, rates and changes-of-rate, throughout the engagement? Were the values too high for the different marks of Dreyer Table in Beatty's ships? Did the conditions unduly favour the German rangetakers? And why did Hipper's ships shoot so much better, even though, apparently, they were equipped with a fire control system more rudimentary than the Dreyer Table Mark I? All these issues require a detailed, quantified analysis if the true causes of Beatty's defeat are to be determined.

At the very end of the War, Beatty set up the 'Dreyer Table Committee' to consider improvements and standardisation of existing tables and to make recommendations for future developments. Respecting existing tables:

> the rectification of a number of problems made "a considerable alteration in design" necessary. "Many complaints"...had been received with regard to the unsatisfactory performance of the clock drive'.

However, like the earlier Phillpotts Committee, they explicitly rejected true-course plotting. The new Admiralty Fire Control Tables incorporated 'the infinitely variable speed drive of the Argo Clock' but the plotting arrangements remain unclear. The text of *In Defence of Naval Supremacy* refers to: 'the adoption of both automatic rate and true-course plotters - which in effect was what was done after the war' but a footnote states:

> ...Pollen's final true-course plotter...may or not have been practicable....The incorporation of rate rather than true-course plotting in the post-war British fire control system does not necessarily signify much....it could be argued that [this] was influenced by the view that future naval engagements would involve much more frequent changes in course and speed on both sides than had previously been the case, under which circumstances a true-course plot might be of less value than a rate-plot.[32]

Thus the question remains open of whether the Argo true-course plotter could have obtained enemy course and speed as both sides altered course several times during the Run to the South.

In his closing chapter, Sumida reaches the following conclusions.

[31] *IDNS*, p.301.
[32] *ibid.* pp.310-3,315, 331 and 339.

> Consistent results with optical rangefinders were difficult to achieve, high speed and changing courses resulted in ship motion that interfered with gun-laying, even when director firing was employed, and neither rate nor probably true course plotting by themselves were capable of producing satisfactory results under difficult conditions. It cannot be doubted, however, that full Admiralty cooperation with Pollen's efforts would have resulted in the putting into service of a fire control system that was far superior to that...actually adopted [and which] almost certainly would have enabled British ships to hit more often - perhaps even much more often - when range and bearing rates were high and changing.

Several factors contributed to the rejection of the Argo system.

> Admiralty objections to the cost...arose from a failure to recognise...that Pollen's prices of necessity had to cover high research and development expenses, and the purchase of manufacturing facilities...In retrospect, his financial demands seem to have been reasonable.

However, Sumida concedes that Pollen:

> ...was probably ill-suited by nature to work easily with naval officers [and his] communications with political leaders, businessmen and journalists...while of great use of occasion in overcoming opposition, was undoubtedly feared and resented by his service opponents.

On the other side:

> ...the Admiralty was generally distrustful of inventors, and though more open to the adoption of perfected new weapons than is perhaps generally supposed, was as unwilling as other departments then were to support research and development. Most naval officers, by education and experience were not equipped to deal with technical issues....
>
> ....
>
> The negative effects of Pollen's background and personal shortcomings...were much exacerbated by...the obstinacy and technical ignorance of Wilson and Bacon, and the zeal and ambition of Dreyer [while] Fisher...lacked the technical knowledge to make informed decisions on his own....
>
> ...The Ordnance Department [was] overwhelmed with routine paperwork [allowing] little time to give important policy matters proper consideration....In addition [it] lacked a permanent staff of technicians expert in fire control....
>
> In the absence of firm direction from the top and consistent direction from the Ordnance Department, Pollen's work was disrupted and delayed by the action of a powerful service clique....By the time Pollen was able to put forward a practicable set of instruments [his] opponents...were able to obfuscate the technical issues by offering an alternative, which if derivative and inferior, was nonetheless an improvement on existing instruments.
>
> ....
>
> ...the resulting lack of an effective system of fire control, in combination with the deployment of inadequately protected battle cruisers and the excessive volatility of British ammunition, was to have disastrous consequences at the battle of Jutland.[33]

Yet even this admirable summary raises further issues; the limitations imposed by rangefinder accuracy: Pollen's financial management: his frequently antagonistic

[33] *ibid.* pp.331-5.

relationships with Admiralty officers: and the level of resources available to the Ordnance Department and the extent to which they were able to support research and development on unperfected new instruments. Lastly, there is the imputation of technical ignorance amongst senior officers. This is an unexpected criticism of a naval elite which is usually said to have been much too concerned with material and technical matters.[34] In fact, Fisher had an aptitude for mathematics, had been responsible for early experiments in the electrical firing of guns and mines and had been Captain of HMS *Excellent* and Director of Naval Ordnance. Both Wilson and Bacon were torpedo specialists and so were familiar with some of the most advanced technology of their time, including gyroscopes and applications of electricity: while Wilson is elsewhere allowed sufficient understanding of the arcana of fire control to be accused of 'subtle prevarication'. Jackson qualified as a torpedo lieutenant and was Assistant DNO (with responsibilities for torpedoes) before becoming Captain of *Vernon* in 1904: while his pioneering work on wireless earned him a Fellowship of the Royal Society. Only Moore is omitted from these strictures, but he was a gunnery officer who had specialised in mathematical theory and had a reputation for cleverness.[35] None of these officers would have had difficulty in understanding either the technical principles or the mechanisms of the fire control instruments.

This introduction has posed many questions: on the influences, in both directions, between Argo designs and Service instruments: on the choices made by the Admiralty at several critical stages in the evolution of the Argo system: and on the consequences at Jutland of the final decision in favour of the Dreyer Tables. However, before addressing these issues, the essentials of long range gunnery at sea and, in particular, the fundamental concepts of rate and change-of-rate, must first be considered.

[34] K G B Dewar, *The Navy from Within* (London, 1939) pp.58-64. Gordon, *Rules of the Game* (*op. cit.*) p.381. Arthur Marder, *From the Dreadnought to Scapa Flow, Volume I* (London, 1961) p.401.
[35] Ruddock F Mackay, *Fisher of Kilverstone* (Oxford, 1973) pp.22-3,44-6,100,173,187 and 193. *IDNS*, pp.91 and 121. Gordon, *Rules of the Game*, pp.167,369 and 383: Beatty thought Moore 'too clever'. Moore's Service Record, ADM 196/42, p.64. Adrian Blond, 'The Papers of Sir Henry Jackson 1855-1929' in *New Researchers in Maritime History, Papers presented at the Third Annual Conference 18 March 1995*, Royal Naval Museum, Portsmouth. *DNB 1922-1930*, pp.448-450.

2

Long Range Naval Gunnery

The simplest possible conditions for gunnery at sea are found when the opposing ships are steaming on identical courses at equal speeds; hence both the range and the target bearing remain constant. At all but point-blank ranges, a shell follows an approximately parabolic trajectory; thus, to hit, the gun must be elevated at the correct angle relative to the line-of-bearing that joins the point of aim on the target to the centre of the gun's trunnion axis. Also, the rifling imparts a stabilising spin which, in British guns, caused the shell to drift to the right, by several hundred yards at long range;[1] a corresponding deflection to the left was therefore necessary. Accurate fire at long range demanded precise telescopic gun sights (Plate 1) for the gun layer (who controlled his gun's elevation) and the trainer.[2] Relative to the gun axis, the telescopes were deflected horizontally by an equal but opposite angle to the required deflection angle: and depressed by the required angle of elevation. Thus, the guns would be correctly elevated and deflected relative to the line-of-bearing if they were fired only when the point-of-aim lay under the telescopes' cross-wires. From a ship at once rolling, pitching and yawing, accurate shooting in salvoes required continuous aim: that is, as far as possible, the guns were elevated and trained to keep the telescopes always on the point-of-aim.[3] In British turrets, the guns were aimed hydraulically, each gun having its own elevating cylinder, while a hydraulic engine trained the whole turret; good shooting by the heavy guns demanded powerful hydraulics yet easily manipulated and responsive controls.

[1] *Text Book of Gunnery Part I*, compiled at the Ordnance College, Woolwich, London, 1907, p.72, NMM.
[2] For the layout in turrets, see John Roberts, *The Battleship Dreadnought* (London, 1992) pp.218 and 222 (copy, courtesy of the author, gratefully acknowledged).
[3] *Manual of Gunnery Vol. III for His Majesty's Fleet 1911*, p.3, Ja 254, AL.

Gun sights were calibrated directly in ranges so that, for any range set on the sight, the angle of the layer's telescope to the gun barrel equalled the angle of elevation in the gun's standard range table. Of course, when shooting at sea, the conditions were almost always different from those in use when the tables were compiled. The ranging of all guns was affected by differences in atmospheric temperature and humidity (and hence drag) and cordite temperature. The trajectory of the shell was also influence by wind along the range, although the necessary corrections could not always be estimated accurately from the wind-speed at sea-level.[4] The performance of individual guns was also affected by barrel wear and manufacturing tolerances. Thus the gun ranges actually set on the gun sights were usually different from the true (or geometric) range, and incorporated the common corrections (the 'error of the day') plus, for the older geared sights like that in the plate, the corrections for individual guns.[5]

However, there was also considerable uncertainty in the true range itself, which could only be measured by optical rangefinder. Even at Jutland, all the battlecruisers still depended on the 9-foot Barr and Stroud FQ2 coincidence rangefinder. In theory, the uncertainty of observation for these instruments was 85 yards at 10,000 yards, increasing to 190 yards at 15,000 yards.[6] However, in use, random errors in range could be much larger. In 1913, *Thunderer*, taking eight ranges per minute with three rangefinders, observed an average spread of 700 yards at 9,800 yards:[7] while, at Jutland, *Iron Duke* noted: 'Error reported by Rangefinder Plot was 500 yards. Range 11,000 yards'.[8] In post-War trials, a consistency (assumed to be equivalent to half the mean spread) of 185-330 yards was obtained when taking about 3½ ranges per minute between 12,500 and 14,000 yard.[9] Consistency and spread were measures of the random errors about the mean of a single series of observations; however, every observation in a series could also

[4] For a range of 16,000 yards, a 13.5-inch shell reached an altitude of 2,664 feet: Admiralty, Gunnery Branch, *Range Tables for His Majesty's Fleet, 1918, Vol. I*, p.150, ADM 186/236, PRO. Likewise, deflection required correction for wind across the range: *ibid.* pp.10-17.

[5] Arthur Pollen, 'A.C.: a Postscript', 1905 in Jon Sumida (ed.) *The Pollen Papers* (London, 1984), pp.59-60.

[6] *The Barr and Stroud Rangefinders* issued by Barr and Stroud ... Glasgow, 1906, p.19, Ja 190, AL.

[7] 'Summary of Results' and *Thunderer*, 'Report on Firings carried out at "Empress of India" 8 November 1913' in 'Gunnery Practice at Sea: Sinking of HMS Empress of India 4/11/13' in ADM 1/8346.

[8] Commander Blake, *Iron Duke*, 'Notes made in the...Gun Control Tower' in ADM 137/302. 'Error' here is assumed to be the same as 'spread'.

[9] Admiralty, Gunnery Branch, *Progress in Gunnery Material 1922 and 1923*, p.38, ADM 186/259. Although these consistencies were obtained in a destroyer at high speed, they were 'only very slightly increased' from those obtained by the usual method of rangetaking, which 'has been found to provide just over four ranges per minute under vibrationless conditions'. Consistency was the average variation (deviation) from the mean of a series of ranges: *ibid.* p.47.

be skewed from the true value by a systematic error. Thus both random and systematic errors may be included in the warning that: 'a single range observation may [be] at 16,000 yards easily as much as 600, 700 or even 800 yards from the truth'.[10] Later in the War, systematic errors of up to 1,000 yards or more, high and low, were sometimes obtained, although the relative changes of range within a single series were normally not serious affected. These phenomena were investigated during and after the War; the rather tentative conclusion was that they were due to a combination of the effects of atmospheric refraction and temperature, aggravated by uneven heating of the rangefinder tube, if the instrument was in direct sunlight.[11]

Thus, when fire was opened, even if the true range was unchanging, the range on the gunsights was unlikely to find the target with the first shots.

> We know that, broadly speaking, the initial range is never right.[12]

It was then necessary to correct the unknown (and unknowable) errors by observing the fall of shot and systematically correcting first the deflection (so that the shots were falling on the line-of-bearing, either in front of or behind the target) and then the gun-range. This process, called spotting, was only practicable if the guns were fired in salvoes; the splashes from the individual rounds could then be judged as a group, in which the inevitable variations due to aiming, propellant and other ballistic factors could be averaged by eye. At 12,000 yards, the typical salvo spreads for range were 200 yards for 15-inch guns, 300 yards for 13.5-inch and 400 yards for 12-inch.[13] Spotting was regarded as a necessary evil.

> In all fire-control systems, good spotting is the first essential of hitting. This, however, does not alter the fact that the less a system is dependent on spotting the better, since spotting in its turn is dependent on a clear view of the object fired at.[14]

Spotting for range used the system called bracketing, which is illustrated in Fig. 2.1. Essentially, whenever the target was crossed (i.e. two successive salvoes fell on opposite

[10] F C Dreyer and C V Usborne, *Pollen Aim Correction System. Part I. Technical History and Technical Comparison with Commander F.C. Dreyer's Fire Control System*, printed May 1913, p.19, P.1024, AL.
[11] *Grand Fleet Gunnery and Torpedo Orders*, 312. 'Rangefinder Errors', 29 December 1917 and 106, 'Rangefinder errors', 5 October 1918, ADM 137/293 (new numbering sequence from May 1918). Admiralty, Technical History Section, 'Fire Control in H.M. Ships' (TH23), pp.33-4 in *The Technical History and Index, A Serial History of Technical Problems dealt with by Admiralty Departments, 1919*, AL. Admiralty, Gunnery Branch, *Progress in Gunnery Material 1921*, p.9, ADM 186/251 and *PGM 1922-3* (*op. cit.*) p.53.
[12] Reginald Plunkett, 'Notes on "Rate" ', March 1911 in DRAX 3/4, CC.
[13] Admiralty, Gunnery Branch, *Spotting Rules 1916*, p.4 in Ja 011, AL. See also ADM 137/2028.
[14] Admiralty, Gunnery Branch, *Manual of Gunnery (Volume III) for His Majesty's Fleet 1915*, p.14, Ja 254, AL.

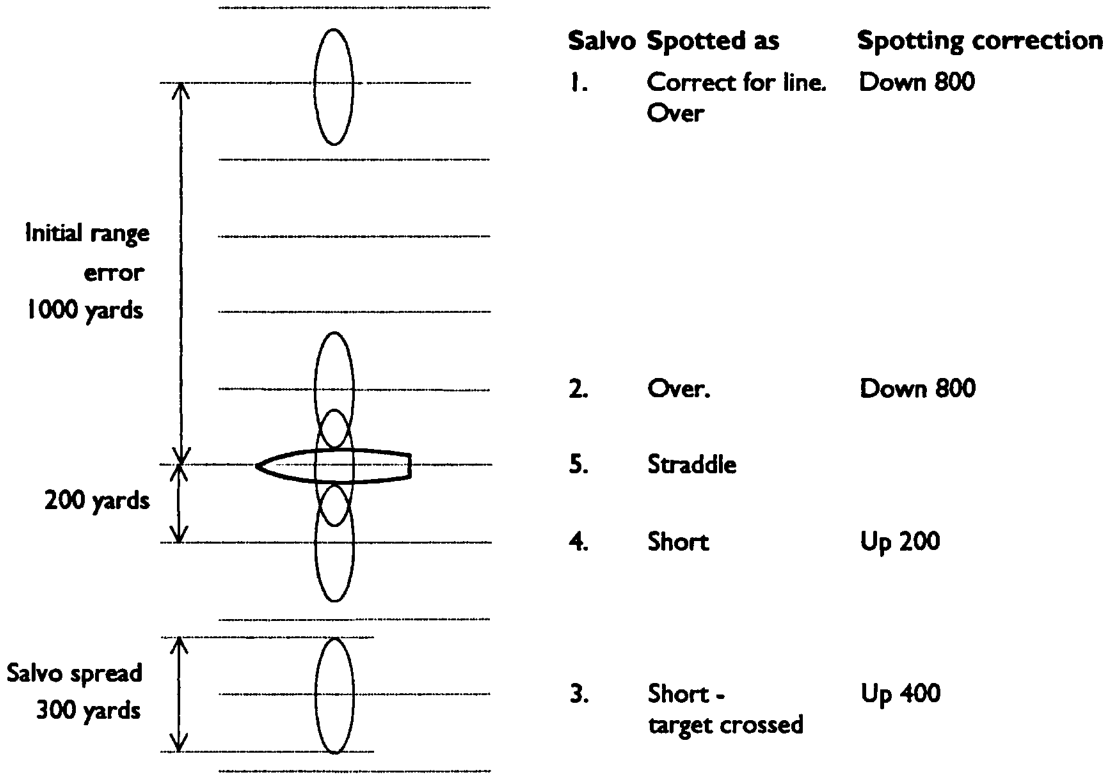


FIG. 2.1: WORKING A BRACKET

sides of the target) the spotting correction applied to the next salvo was in the opposite direction and half the amount of the previous correction. As the figure shows, if the initial range error was 1,000 yards, as many as five salvoes might be required to find the target. Since the interval between spotted salvoes could reach 50 seconds or longer at battle ranges,[15] this might take 3½ minutes; the disadvantage of an inaccurate opening range is clear.

STEADY COURSES

Normally, a firing ship and its target would be on different courses at different speeds. Thus both the ranges and bearings of the target changed with time, even though

[15] At Jutland, *Iron Duke* opened fire just after 6.30 p.m. and fired her first spotted salvoes with intervals of 35, 40 and 50 secs. at a range of 12,000 yards: 'Notes made...in "B" Turret of H.M.S. "Iron Duke" ', ADM 137/302. The intervals between *Derfflinger's* initial spotted salvoes at *Queen Mary* were 40, 65 and 35 seconds at 14,000-13,500 metres: Georg von Hase, *Kiel and Jutland* (London, 1921) p.160.

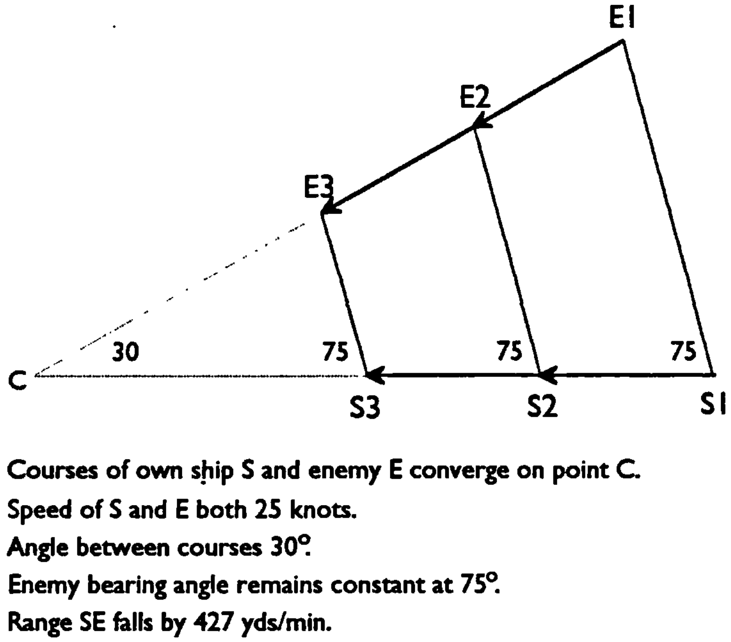


FIG. 2.2: CONSTANT RATE AND BEARING

courses and speeds were steady. While the target remained visible, the trainers could follow any change of bearing: but, to keep hitting, it was vital to predict the change of range between salvoes. Furthermore, at long range, each round took about 30 seconds to reach the target;[16] thus the gun range also needed to be corrected to allow for the change of range in the time-of-flight.

To calculate both changes of range required a knowledge of the rate of change of range: or, more concisely, the range-rate. Consider first the simple case of two 25-knot ships on courses converging at 30° such that, eventually, the two ships would collide (Fig. 2.2). The target bearing of 75° remains constant, but it can be calculated (see below) that, in each minute, the range falls by 437 yards: that is, the range-rate is 437 yards per minute closing i.e. -437 yds/min. From the viewpoint of an observer on the firing ship, the target appears to be moving towards him at this rate along the line-of-bearing; since one knot equals 33.78 yds/min., the apparent or virtual speed of the target is 12.9 knots. Notice that, despite the shallow angle of convergence, this speed is more than 25% of the maximum possible value, the 50 knots closing (-1689 yds/min.) experienced if both ships were headed directly for each other.

[16] 25.7 secs. for a 13.5-inch shell at 16,000 yards: *Range Tables 1918* (*op. cit.*) p.150.

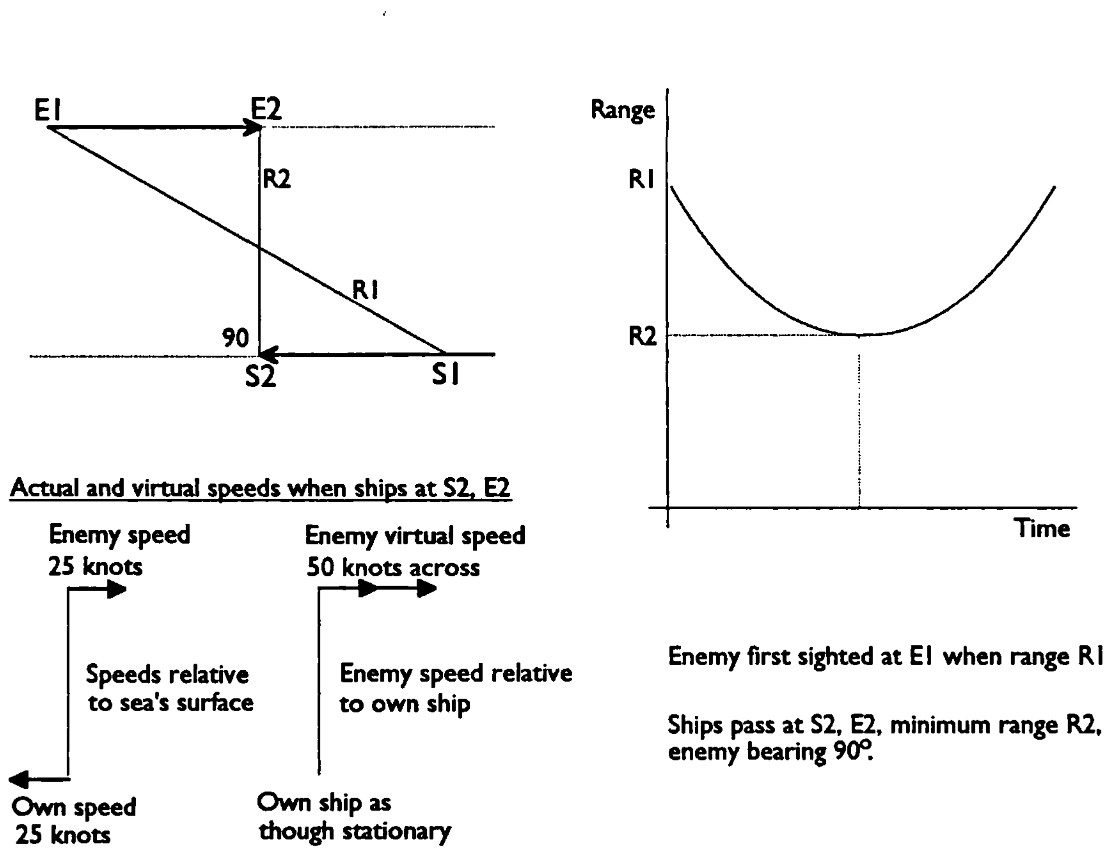
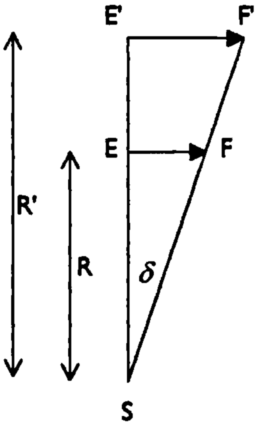


FIG. 2.3: OPPOSITE COURSES: VIRTUAL SPEED ACROSS

Except in special cases, the relative motion of two ships causes changes not only in ranges but in bearings. Fig. 2.3 illustrates an extreme example, again of two 25-knot ships but now on opposite, well-separated courses. Before they pass, the range falls, reaching its minimum value when the ships pass beam-to-beam; then the range begins to increase. If these ranges are plotted against time, the curve has the characteristic shape of a hyperbola, with the greatest curvature at the moment of passing. The range-rate at any time equals the slope of the tangent to the curve; thus the range-rate is initially negative, is momentarily zero and then rises towards the maximum value of +1689 yds/min. As the ships pass, to an observer on the firing ship the virtual speed of the target along the line-of-bearing is zero: but, in contrast, the target appears to be crossing the line-of-bearing at a virtual speed of 50 knots. This large 'speed-across' induces a rapid rate of change of target bearing (a rapid bearing-rate); the resultant change in bearing during the time-of-flight must be allowed for by applying a suitable additional deflection (in this case to the right) on the gunsights. As Fig. 2.4 demonstrates, at short ranges the



E and E′ represent enemy ships at two ranges R and R′ from own ship.

This is a virtual course diagram representing movements relative to own ship S, which therefore appears stationary.

Let the component of the enemy's virtual speed across the line-of bearing be x (any component of speed along is disregarded here). EF and E′F′ represent the travel of the enemy perpendicular to the line-of-bearing in the time of flight of the shells.

Let the muzzle velocity be m. At short ranges, the trajectories are flat and there is no significant loss in velocity in flight. Therefore, the times of flight at the two ranges are $\frac{R}{m}$ and $\frac{R'}{m}$.

Thus $\quad EF = \frac{Rx}{m} \quad$ and $\quad E'F' = \frac{R'x}{m}$.

Hence, in both cases, the deflection angle is:

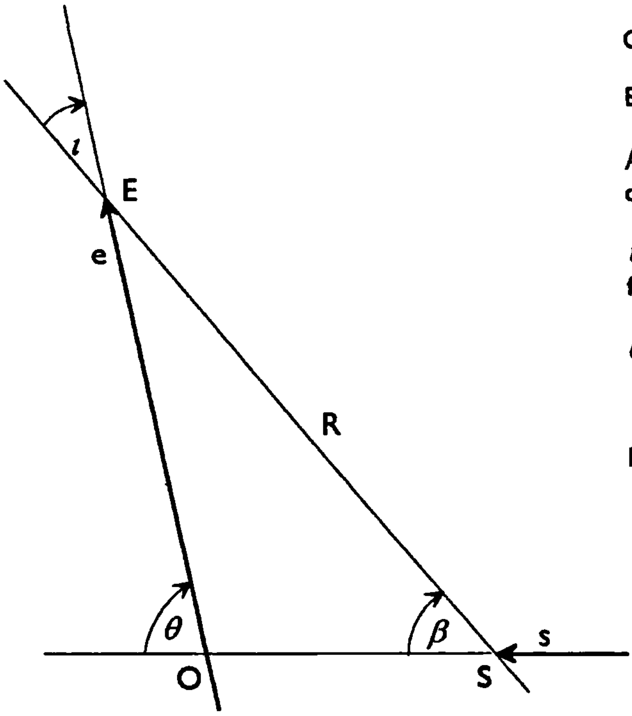
$$\delta = \tan^{-1}\frac{x}{m} \simeq \frac{x}{m}$$

FIG. 2.4: DEFLECTION

deflection angle is range-independent and must be proportional to the speed-across; for this reason, gunsights and other instruments were calibrated for deflection in knots of speed-across:[17] even though, at long ranges, the actual speed-across had to be adjusted upwards to obtain the correct gun deflection to put on the sights.

Fig. 2.5 introduces the general case of two ships on different courses at different speeds; it is drawn thus to make all angles positive (when measured clockwise in the manner of compass bearings) and less than 90°. The change of the ranges and bearings of the enemy (target) ship as seen by an observer on own (firing) ship can be represented mathematically in two ways. The first is in terms of virtual course, which expresses the apparent direction and speed of movement of the enemy relative to own ship. As shown in Fig. 2.6, the virtual course is found by the triangle of velocities which subtracts own speed and course from enemy speed and course. Then, as in Appendix I, it can be shown that the apparent enemy movement along the virtual course line results in a time-and-range curve which is *always* a hyperbola. However, the examples in Fig. 2.7 demonstrate that the curvature depends greatly on the magnitude of the virtual course and the minimum possible range for the courses being considered. In many cases, the curvature is small; either because the hyperbola is flat: or because the action ranges always lie on a part of

[17] Peter Padfield, *Guns at Sea* (London, 1974) p.199.



Own ship S, speed s.

Enemy ship E, speed e.

β is the enemy bearing from own ship's course line.

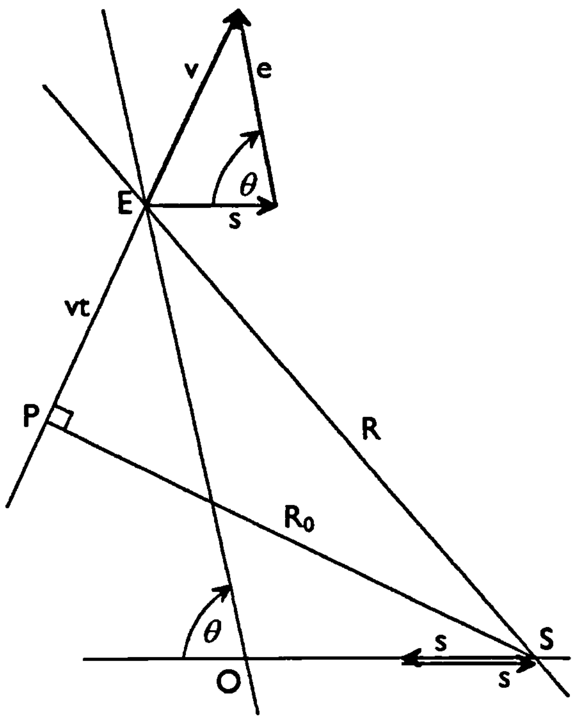
ι is the inclination of the enemy course from the line-of-bearing

θ is the angle between courses

$$\theta = \iota + \beta$$

R (the length of SE) is the True range.

FIG. 2.5: STEADY COURSES AND SPEEDS



v is virtual speed

$v^2 = s^2 + e^2 - 2es\cos\theta$

From the right angled triangle SPE:

$R^2 = R_0{}^2 + (vt)^2$

where $t = 0$ when $R = R_0$.

In the standard hyperbolic form:

$$\frac{R^2}{R_0{}^2} - \frac{t^2}{\frac{R_0{}^2}{v^2}} = 1$$

Own speed s subtracted from the velocities of both ships.

Relative motion is preserved but own ship is rendered as though stationary

FIG. 2.6: VIRTUAL COURSE

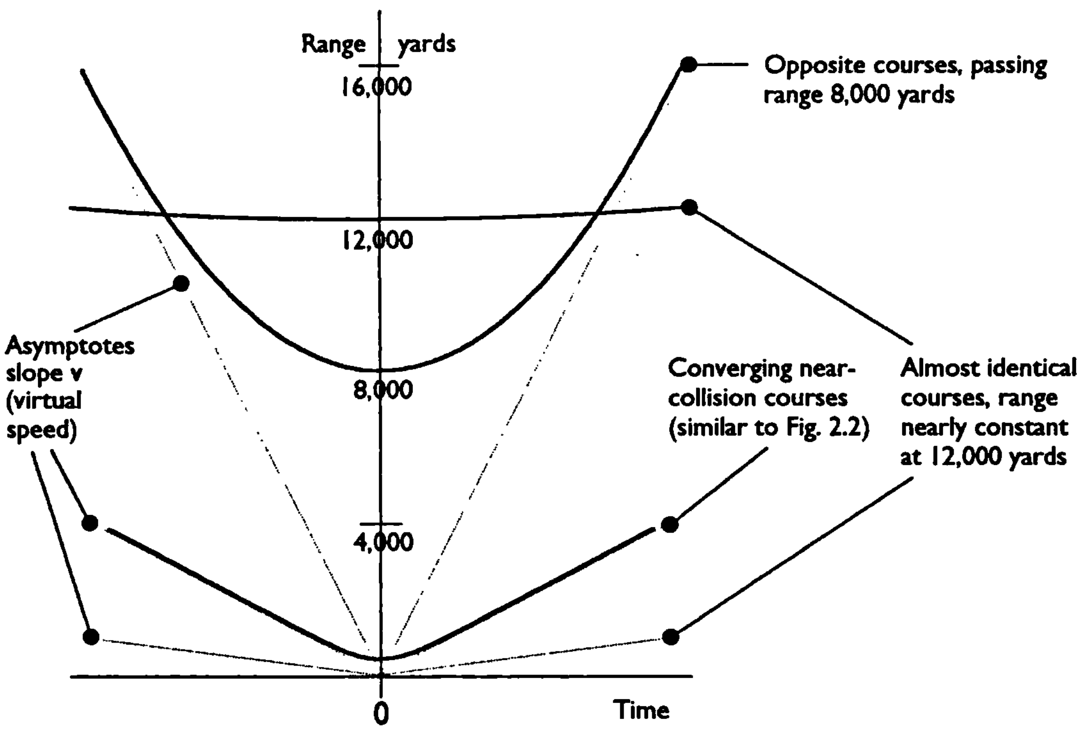


FIG. 2.7: RANGE-TIME HYPERBOLAE

the hyperbola which is nearly straight.[18] However, when ships are passing on (roughly) opposite courses and the range is close to the minimum value, the action ranges fall on a sharply curved part of the plot.

Another way of looking at the rates and change of rates is to resolve the virtual speed into separate components, the speeds along and across the line-of-bearing (as in Fig. 2.8). The speed-along (a), when converted from knots into yards per minute, is a direct measure of the range-rate, which can be represented in the Newtonian notation by $\dot{R}$ ('R-dot'). The speed-across (x), after adjustment for range, gives the deflection for the gunsights and is also used to calculate the bearing-rate, $\dot{\beta}$. Using the symbols defined in Fig. 2.5, the following equations are derived in Appendix II:

$$a = e\cos\iota - s\cos\beta \quad \text{knots} \qquad (2:1)$$

$$\dot{R} = 33.78\, a \quad \text{yds/min.} \qquad (2:2)$$

$$x = e\sin\iota + s\sin\beta \quad \text{knots} \qquad (2:3)$$

$$\dot{\beta} = 1935.\frac{x}{R} \quad {}^\circ\text{/min.} \qquad (2:4)$$

[18] These are the parts which lie close to the straight asymptotes.

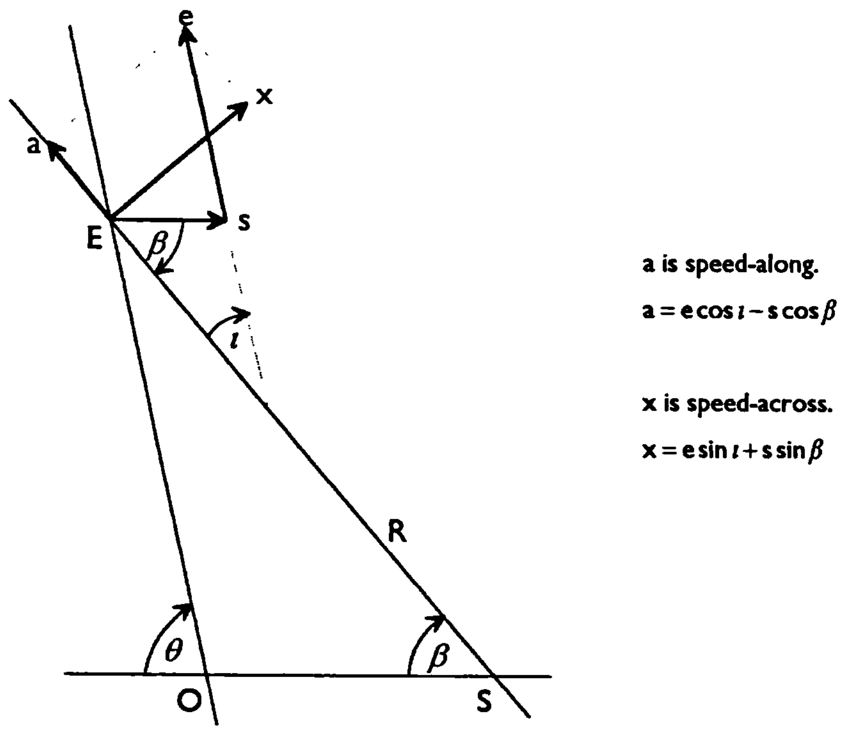


FIG. 2.8: SPEEDS ALONG AND ACROSS

$$\theta = \beta + \iota \qquad \theta \text{ constant when courses steady} \qquad (2:5)$$

where e and s are in knots and R is in yards.

A simple equation can also be derived for the rate of change of range-rate $\ddot{R}$ ('R double-dot'); this is at once a measure of the curvature of the time-and-range plot and of how fast the speed-along is changing ($\dot{a}$).

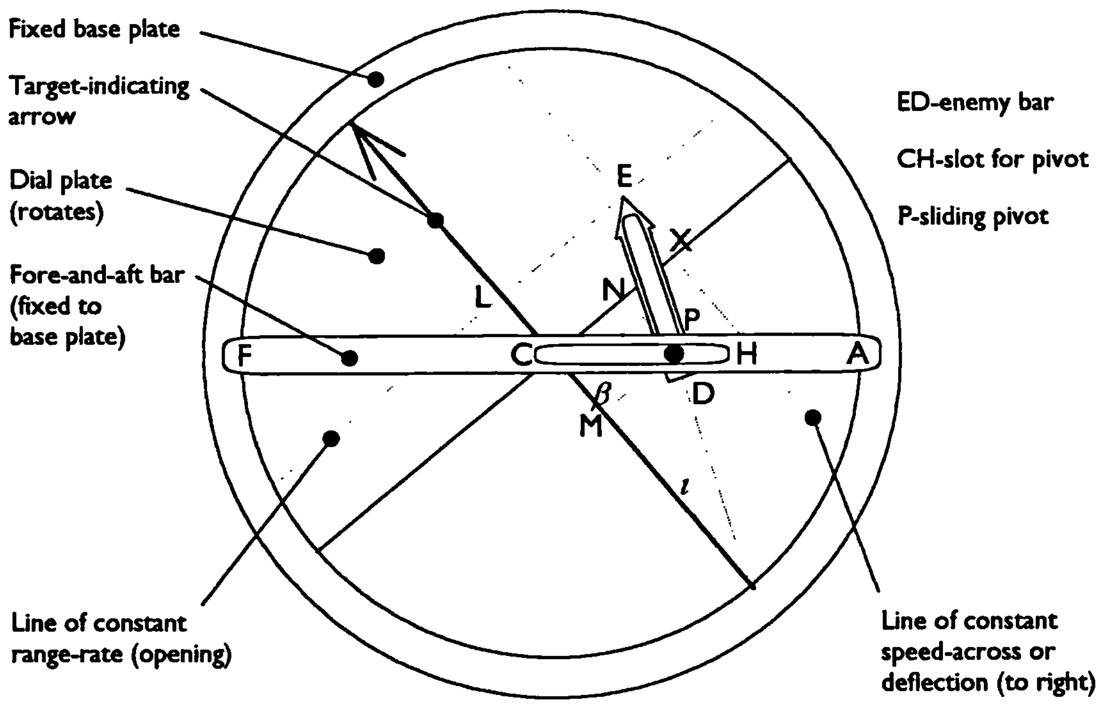
$$\ddot{R} = \dot{a} = 1141 \,.\, \frac{x^2}{R} \text{ yds/min/min.} \qquad (2:6)$$

Similarly, $\dot{x}$ represents the rate of change of speed-across, while $\ddot{\beta}$ is a measure of the curvature of a plot of time-and-bearing.

$$\dot{x} = -33.78 \,.\, \frac{ax}{R} \text{ knots/min.} \qquad (2:7)$$

$$\ddot{\beta} = -130759 \,.\, \frac{ax}{R^2} \qquad (2:8)$$

Equations 2:4-6 establish that, when the speed-across x was high, the bearing β, inclination ι and range-rate $\dot{R}$ all changed rapidly. In action, there was no time for trigonometrical calculations but an instrument to keep the rates automatically, named the Dumaresq after its inventor, was soon introduced (Plate 2). Its essentials are illustrated in



PE = e, enemy speed.
PM perpendicular to LCM.

$$CL = ML - CM = e\cos\iota - s\cos\beta$$

CP = s, own ship's speed.
PN perpendicular to CNX.

$$CX = CN + NX = s\sin\beta + e\sin\iota$$

FIG. 2.9: PRINCIPLES OF THE DUMARESQ

Fig. 2.9, which demonstrates that it was an exact analogue of equations 2:1 and 2:3. In use, the sliding pivot was positioned at a distance from the centre proportional to own speed. The enemy bar was rotated about the pivot so that the angle between it and the fixed fore-and-aft bar equalled the angle between courses; it was also pulled out so that the distance from pointer to pivot was proportional to enemy speed. If the dial plate was then rotated until the large arrow pointed at the target, the enemy bar pointer indicated, on the dial's engraved lines, the present values of range-rate and speed-across; the latter was also called the Dumaresq deflection. Furthermore, if any change in target bearing was followed with the arrow, the changing values of range-rate and deflection could be read off.

If the range-rate was almost constant, keeping the range from salvo to salvo was not too difficult: but, if the rate was changing rapidly, a range-keeping instrument was essential. This function was provided by the Vickers clock (Plate 3), on which a hand rotated against a circular range scale at a speed which was set, if necessary at frequent intervals, to be proportional to the range-rate from the Dumaresq. Thus the clock integrated the range-rate to give the range.[19] When fire was opened, the clock was set with a gun-range based on the latest rangefinder ranges corrected for the error of the day. Although this was unlikely to find the target immediately, if the Dumaresq had been set with the correct enemy speed and course, the clock could continue to follow the

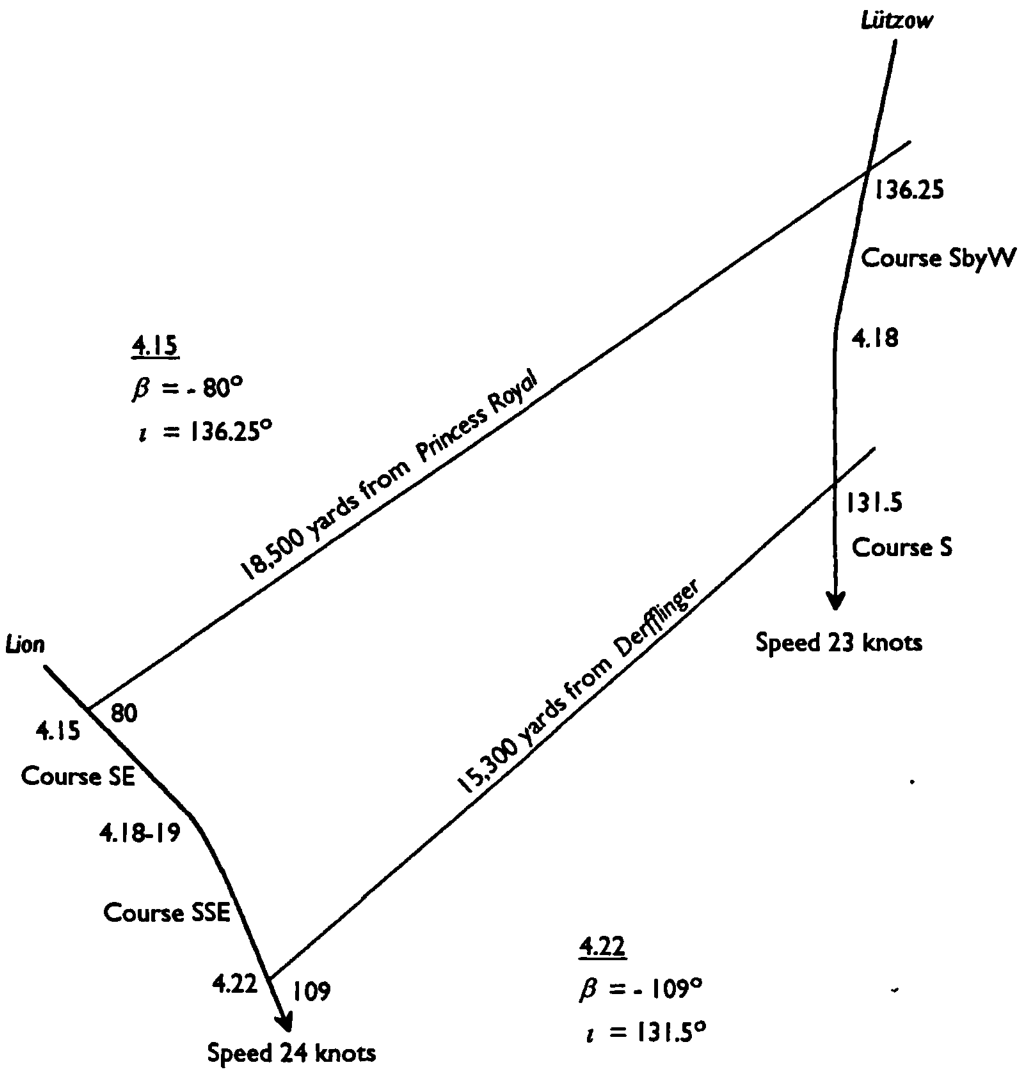


FIG. 2.10: RUN TO THE SOUTH, 4.15 - 4.22

[19] The errors arising from the stepwise setting of the range-rate are discussed in Chapter 3.

subsequent changes of range. Thus the spotter could use the method of brackets, as already described for fixed ranges, to eliminate the opening error and straddle the target. Furthermore, as discussed in Appendix II, the same procedure was the best that could be done even if the initial values of enemy speed and course were wrong; however, while in most cases the target could still be straddled, the rate errors meant that it would be lost again. Further spotting corrections were then necessary to correct first the deflection and then both range and range-rate together. This 'rate spotting' used simple rules of thumb; those recommended in 1915 accompanied each range correction by a rate correction of half the magnitude[20] e.g. UP 200 (yards) and OPEN 100 (yds/min.). If the spotted corrections for deflection and range-rate were also put on the Dumaresq by adjusting the enemy bar, the corrected enemy speed and course were closer to the true values; thus, subsequently, the instrument could keep the rate more accurately. Rate spotting was also the quickest method to correct the rate if it was lost because the enemy altered course to avoid further hits.[21]

The fire-control equations can be used to calculate the actual values of rate and change of rate experienced during the wartime engagements. For example, as described in Chapter 6 and tabulated overleaf, at the start of the second phase of the Run to the South, while *Lützow* steered SbyW at 23 knots, *Lion* made a steep SE'ly approach, speed 24 knots; then, at 4.18-19, both turned away to courses of S and SSE, respectively (Fig. 2.10).

Time	*Lion's* course	*Lützow's* course	*Lion's* target bearing	Range yards	$\dot{R}$ yds/min	$\ddot{R}$ yds/min/min	x knots	$\dot{\beta}$ °/min	$\ddot{\beta}$ °/min/min
4.15	SE	SbyW	-80°	18,500	-702	6.25	-7.73	-0.81	-0.06
4.22	SSE	S	-109°	15,300	-251	2.23	-5.47	-0.69	-0.02

Courses were converging, so that the speed-across was quite low, though not insignificant. However, $\ddot{R}$, being proportional to x^2, was very low; so long as *Lion* held her course, $\dot{R}$ was essentially constant. Similarly, $\ddot{\beta}$ was also small, so that deflection also remained constant. Thus, in this typical tactical sequence of an approach followed by turns onto courses suitable for opening fire, the only cause of rapid change of range-rate was the turn

[20] *Manual of Gunnery 1918* (*op. cit.*) p.15.
[21] *Manual of Gunnery 1915*, p.15 and *Spotting Rules 1916* p.14. (both *op. cit.*).

itself, which almost halved the range-rate. Notice also the much smaller proportionate change in speed-across.

CHANGING COURSES

Small course changes (normally two points but one point at high speed) could be made without interfering with gunnery:[22] provided, of course, that the rates were kept by adjusting the Dumaresq angles, at least approximately, for the changes both in target bearing and the angle between courses. However, larger and faster turns were much more disruptive. Firstly:

> ...at speeds from 12 to 16 knots the loss of speed is from 5 to 8 knots for turns over 4 points. When steadied...speed...is gradually increased by about one knot per minute until the original speed is attained.[23]

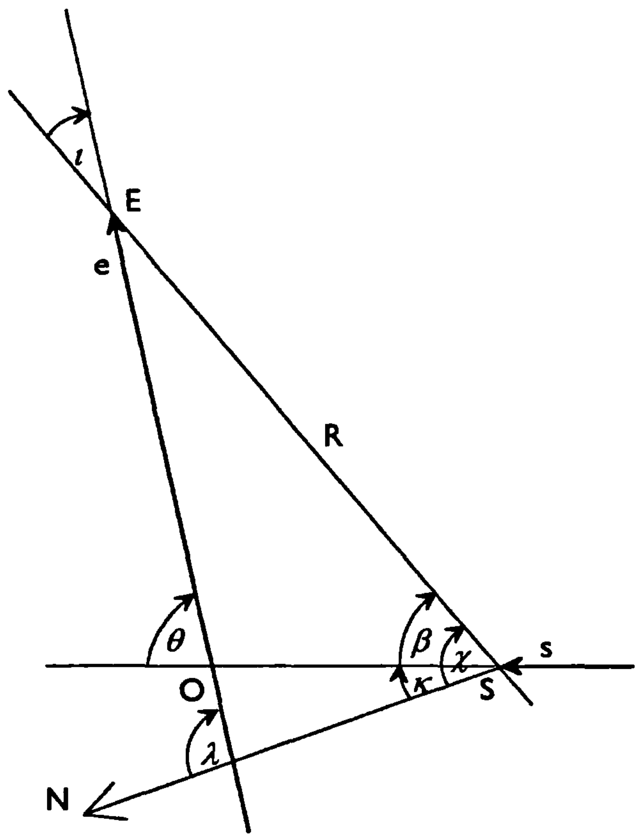
Secondly, under more severe helm, the ship tended to slip sideways, so the course line no longer corresponded with the keel-line; this could result in range errors of one to two hundred yards. Thirdly, heel and vibration could cause other difficulties, notably in taking ranges and bearings from positions aloft; in the battleship *Bellerophon* at full speed, 'our mast-head shook like an aspen each time the helm was used'. Aiming was also more difficult.[24]

Even under helm, equations 2:1-3, which give *instantaneous* speeds and rate, still apply. However, the change in bearing due to speed-across can no longer be expressed relative to own-ship's course-line, which, due to the turn, is itself swinging relative to the line-of-bearing. A new diagram (Fig. 2.11) is needed to introduce a fixed directional reference line pointing North (e.g. as indicated by a gyro compass). If χ represents the target *compass* course, then the momentary change in χ is due only to the momentary speed-across and is independent of the change of course.

$$\dot{\chi} = 1935.\frac{X}{R} \ {}^{\circ}/\text{min.} \qquad (2:9)$$

Similarly, whether a ship is on a dead steady course, yaws about a nominal course or turns, the speed-across, after correction for range, can always be used in determining the gun deflection.

[22] '80. Further remarks on action of 24 January 1915' in 'Secret Packs of the C.-in-C. Grand Fleet. Operations', ADM 137/1943.
[23] *Manual of Gunnery 1915*, p.173.
[24] *Technical Comparison* (*op. cit.*) pp.18, 20 and 36. C V Usborne, *Blast and Counterblast* (London, 1935) p.9. Lord Chatfield, *The Navy and Defence* (London, 1942) pp.109 and 134.



κ is own ship's compass course.

χ is the enemy's compass bearing.

$$\chi = \beta + \kappa$$

λ is the enemy's compass course.

$$\lambda = \iota + \chi$$
$$= \theta + \kappa$$

$$\dot{\chi} = 1935.\frac{x}{R} \text{ °/min.}$$

FIG. 2.11: COMPASS BEARINGS AND COURSES

In Appendix III, extended equations are derived for $\ddot{R}$, $\dot{x}$ and $\ddot{\beta}$ when courses are changing. Although approximate (they assume no change of speed in a turn), they confirm a conclusion implicit in the values for Jutland in the above table. In *all* tactical circumstances, turns of a point or more result in substantial changes in range-rate, deflection or both; in contrast, when courses are steady, rapid changes in range-rate occur only in limited (and rather uncommon) circumstances, when the speed-across is close to the sum of the speeds of the two ships. For example, if a 25-knot ship alters course at 20°/min. with a target abeam,[25] the rate of change of range-rate $\ddot{R}$ due to the turn is ±295 yds/min/min. (the sign depending on the direction of the turn); in contrast, when

[25] *Lion's* rate of turn did not exceed this value during the Run to the South: 'Record of events during action of May 31st compiled from records kept in Control Position and Transmitting Station. H.M.S. Lion' in BTY 6/6, NMM.

two such ships pass on opposite courses at 16,000 yards, the value of $\ddot{R}$ due to speed-across is only +178 yds/min/min.

PLOTTING PRINCIPLES

Keeping the range and deflection required knowledge of enemy speed and course. Until the invention of inclinometers late in the World War I,[26] neither could not be measured directly but could only be deduced from observations of enemy ranges and bearings. As already remarked, ranges when long were liable to spreads of many hundreds of yards. As shown by the table for Jutland, target bearings could change by less than one degree per minute; yet they had to be measured from ships which, in bad weather, could experience yaws of as much as 6° in two or three seconds.[27] Clearly, some form of gyroscopic yaw correction was needed but, even after the adoption of the first gyrocompasses, accuracy was limited. Despite extensive design changes after it entered service with the Royal Navy, the Anschütz model still tended to wander slowly by 5-10° in anything except smooth water.[28] Furthermore, the virtual meridian of any gyrocompass (the direction in which it settled) was influenced by own course and speed; in the North Sea, it could change by as much as 2° following a course alteration of 4 points by a 25-knot ship.[29] During the War, Anschütz were replaced by Sperry gyrocompasses, but the Phillpotts Committee concluded in 1918 that they did not yet 'enable own ship's motion to be accurately dealt with'.[30] Another source of uncertainty in bearings was that, until late in the War, bearings could only be transmitted in rather coarse steps of ¼°.[31]

British fire control systems experimented with various forms of plotting, either of enemy course (from which a speed could also be measured) or of target ranges and bearings separately against time.[32] The latter is also called rate plotting, since the rates can

[26] *Technical History*, 1919, pp.30-1.
[27] *PP* (*op. cit.*) 'The *Jupiter* Letters' (1906) p.83. 'Fire Control. An Essay by Captain C Hughes-Onslow, completed August 1909, Section IV, p.5, PLLN 1/5, CC.
[28] A E Fanning, *Steady As She Goes* (London, 1986) pp.177-8.
[29] *The Anschütz Gyro Compass* (London: Elliott Brothers, 1910) pp. 69-70 and 91-2, Elliott Archive. Automatic course correction was available, but only from some makers, by the early 1930s: Fanning (*op. cit.*) p.232 and *The Gyro-Compass and Gyro-Pilot* (London: Sperry Gyroscope, c.1931), author's collection.
[30] Fanning, pp.180 and 196-7. Phillpotts Committee, 'Report of inspection at York of Pollen Fire Control System', n.d. but 1918 in DRYR 2/1, CC. A fully satisfactory gyro compass for gunnery purposes was not developed until WW2: Fanning, pp.233-5.
[31] *Technical History*, 1919 (*op. cit.*) p.27.
[32] See Chapters 3 to 5.

be obtained by measuring the slopes of the plots.[33] Whatever the method, the spreads in ranges and bearings resulted in a scatter of plotted points; as more points were plotted, a mean line approximating to the true 'underlying graph' would begin to be perceptible. As plotting continued, the mean line became a more and more accurate estimate of the underlying graph;[34] a more precise estimate of angle or slope could be expected if the underlying graph was a straight line rather than a curve. An advantage of plotting over calculating the average (manually or mechanically) was that, once the mean line could be made out, each point could be assessed visually against the general trend and given less weight if it appeared at all anomalous.

In all four variants of course plotting, the enemy course was represented by a series of plotted points; as soon as the underlying course could be discerned, the course angle and speed were measured directly off the plot and set on a Dumaresq or some form of range-and-bearing clock. All course plots relied on range-bearing pairs, each pair of values being taken simultaneously. The easiest variant to describe, though the hardest to implement, was true-course plotting (Fig. 2.12a).[35] On a single sheet, which represented the sea's surface, the plotter drew own ship's course as a line which reproduced all changes of direction, whether due to yaw or actual course alterations. Each enemy point was drawn relative to the position on the plot of own course where the range-bearing pair had been recorded. The graph underlying the enemy plot was a straight line while he held his course; if he turned, the new course would be perceptible after a time as a new mean line. If own ship altered course, in theory the enemy course direction would be unchanged: though this depended on the meridian of the gyro reference remaining undisturbed.

A course plotter was much simpler if own course was plotted as a straight line; this line represented the mean of own course, and, initially, enemy bearings were measured relative to a gyroscopic reference set parallel to this mean course. Any subsequent alterations by the enemy could be registered as on the true-course plot. However, if own ship altered course, the plotter, by design, could only continue to draw a straight line, advancing the plotting point at a speed proportional to own-speed. In one

[33] Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) p.217.
[34] 'The best that...mathematical processing [like plotting] can do is to reduce uncertainty in inverse proportion to the square root of the number of (independent) measurements processed': P G Pugh, 'Dreadnought fire control' (unpublished, 22 November 1993), copy gratefully acknowledged.
[35] The choice of these particular relative courses is explained in Chapter 4.

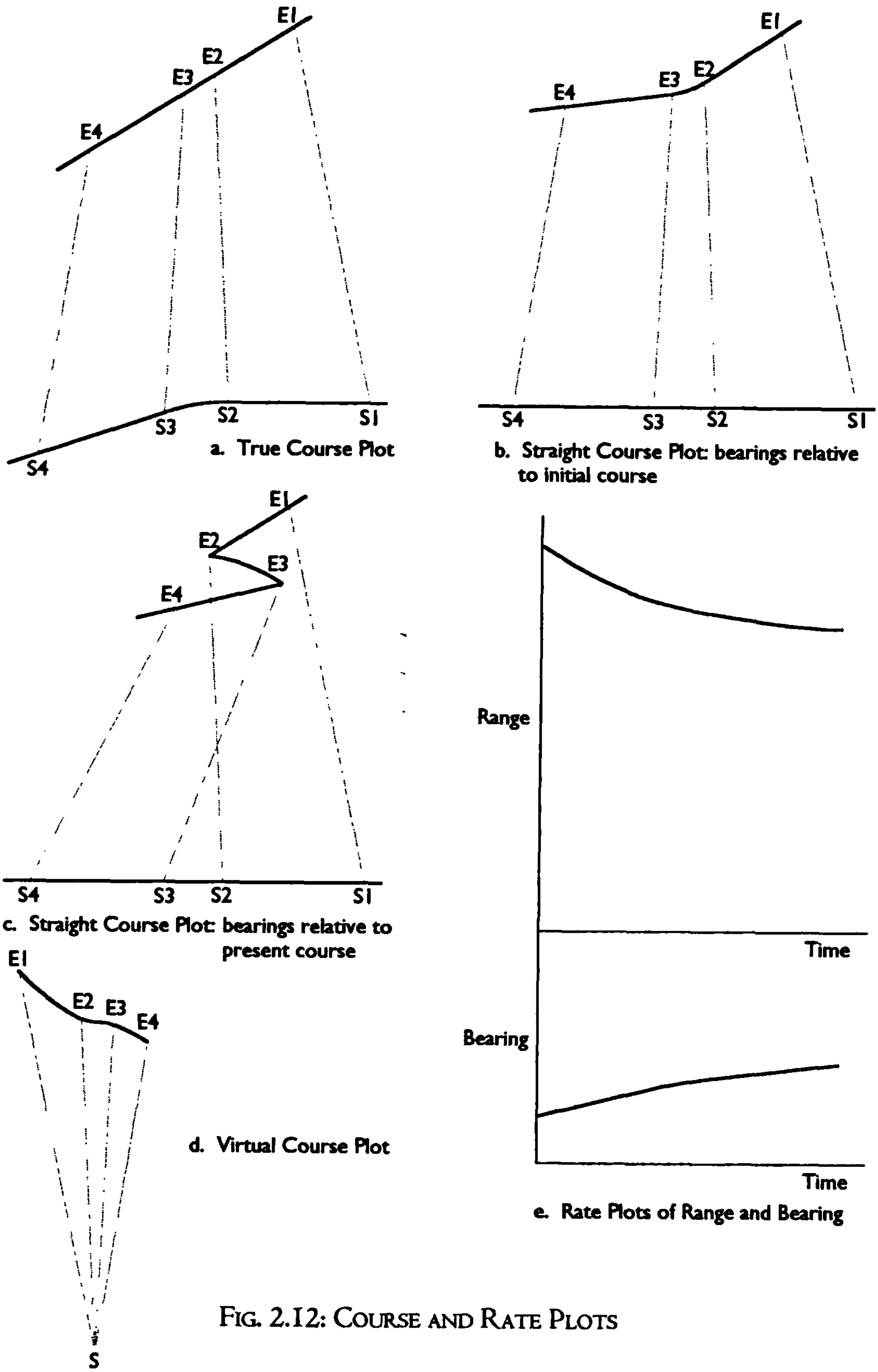


FIG. 2.12: COURSE AND RATE PLOTS

variant of this 'straight-line' plotting, the bearings continued to be measured relative to the old course line; thus the technique required a gyroscopic reference which remained undisturbed by the turn. Fig. 2.12b shows how the true courses illustrated in Fig, 12a would appear on this type of straight-course plot. The enemy course plotted after own ship's turn was not the actual course; however, Appendix IV shows that, if a Dumaresq was set with the apparent enemy course and speed and the enemy bearing measured from the plot, the instrument showed the correct virtual course and speed: and hence indicated the correct range-rate and deflection. In a second variant, the gyroscopic reference was reset to the new course once it had steadied. Through the turn, the plot could trace approximately the resulting large change in target bearing relative to the keel-line (Fig. 2.12c); however, no useful information could be extracted from this portion of the plot; in effect, plotting began again after the turn was completed.

The simplest course-plot to make was that of virtual course, in which the plotting ship was represented by a single point. The virtual enemy course was plotted using ranges and enemy compass bearings: so the directional reference was a compass meridian. Any change in course *or* speed by *either* ship resulted, in general, in a change in virtual course *and* speed (Fig. 2.12d).

While courses and speeds were steady, the underlying graphs of all course plots were straight lines. The plotted points were scattered from their correct values by both range and bearing errors, but, even so, the angle of the enemy course could be measured directly once the mean course line was perceptible. In contrast, enemy speed could not be obtained as a graphically-determined mean; estimates had to be calculated from the distance and time separating pairs of plotted points. However, as shown in Appendix V, in the worst case, the errors of two points, even if separated in time by two minutes, could combine to give speed errors of as much as ±50%; thus it was necessary to repeat the calculation on sufficient pairs until the average of all the calculated speeds converged on a reliable value. The accuracy of the calculations also depended on how precisely the times of the individual points could be inferred from information recorded on the plot (for Argo's use of minute marks, see Chapter 4).

The alternative to course plotting was rate plotting (Fig. 12e). The two plots were made independently, so range and bearing observations did not need to be synchronised. As explained when introducing equation 2:8, the bearing-rate required to determine deflection was the rate for target *compass*-bearings. Ranges from many rangefinders could be used for the time-and-range plot; furthermore, the range clock, which generated predicted ranges, could be treated as just another range source. When speed-across was low, the underlying graphs were almost straight. These were the easiest conditions for discerning first a mean range and then the mean slopes which indicated the range-rate and bearing-rate. Once the bearing-rate had been converted (by equation 2:4) into speed-across, the two rates could be used to set (or to adjust the existing setting of) the Dumaresq by means of a 'cross-cut'. The instrument was set first for enemy bearing and own speed. The enemy bar was then pulled out until its pointer lay at the intersection of the dial graduations for range-rate and speed-across which corresponded with the values obtained from the plot. This automatically set the Dumaresq for the enemy speed and course that would produce those rates.[36] As the plots were continued, their slopes could be compared with the Dumaresq settings in case the latter required further correction; predicted ranges could also be compared with those from the rangefinders. If the enemy altered course, the Dumaresq could be adjusted (in small steps in the manner of rate spotting corrections) as soon as the changes in the slopes were perceptible. If own ship turned, the Dumaresq could indicate, at least approximately, the expected changes in the rates; thus any additional substantial divergence of the plotted rates from those on the Dumaresq would suggest a simultaneous turn by the enemy. However, a turn by own ship could also disturb the gyrocompass, which could render the bearing plot of little use; nonetheless, time-and-range plotting (unlike course plotting) could continue even when bearings were unavailable.

When courses were steady, course plots were always straight. In comparison, if the courses were nearly opposite and the two ships were close to the minimum range, the time-and-range curve was a segment of a sharply curved hyperbola. Thus, with the rate changing rapidly, it was necessary to measure not the mean slope of the whole plot, but the slope of the tangent to the most recent part of the mean line. This may have been possible at medium ranges, where ranges were plentiful and accurate: especially since 'the observer always has the knowledge of which way the curve must be bending theoretically to help him'.[37] For example, if the slope was negative, the curvature was greatest for the

[36] *PP*, p.373.
[37] *Technical Comparison*, p.61. Dreyer and Pollen discussed hyperbolic curves and a 'hyperbolic clock' in 1909 (Chapter 5).

most recent section of the plot, and the tangent could be drawn accordingly. However, as ranges increased, so too did their scatter; the worst case arose when plotting began close to the minimum of the hyperbola and the scatter made it impossible initially to make out any slope at all. Appendix VI shows that, for two 25-knot ships passing at 16,000 yards, the rate from the plot could then lag behind the true rate, though by no more than 180 yds/min. At these ranges, the uncertainty in rangefinder ranges was some 300-400 yards; thus it might take a few minutes before the error became apparent, either in the curvature of the rangefinder plot or its divergence from the clock (predicted) ranges. It could then be corrected by stepwise adjustments to range and rate.

In these special circumstances only, rate plotting was slow in obtaining a sufficiently accurate range-rate. Otherwise, however, rate plotting possessed two distinct advantages over course plotting. Firstly, the scatter of points on the course plot was greater because they were displaced by the errors in both range and bearing; furthermore, since the time-and-range plot could record ranges from many sources, it also had many more points. Thus the mean lines through the rate plots could normally be discerned well before the mean enemy course line of the course plot. Secondly, and more decisively, even after the mean enemy course could be made out, it was very unlikely that a reliable enemy speed could be obtained immediately; a further delay was required to average out the speed errors over additional pairs of points sufficiently separated in time. Thus, except perhaps when the speed-across was exceptionally high, the Dumaresq could be set sooner from rate plots than from a course plot: and, subsequently, the rate plots would continue to give more accurate values.

HIT OR MISS

At the long range of 16,000 yards, the angle of impact of a 13.5-inch shell from *Lion* was 15°. Assuming that the enemy was broadside on, any shell with a trajectory between that ending at the engaged side's water-line and that grazing the top of the superstructure on the opposite side would make a hit. Fig. 2.13 shows that this was equivalent to a spread in range equal to the target width plus the danger-space e.g. for *Lützow* as target, about 67 yards at 16,000 yards (138 yards at 8,000 yards). Thus the effective target lay in the area covered by the target waterline extended on the non-engaged side by the danger-space. Since *Lion's* salvo spread for range was at least 300

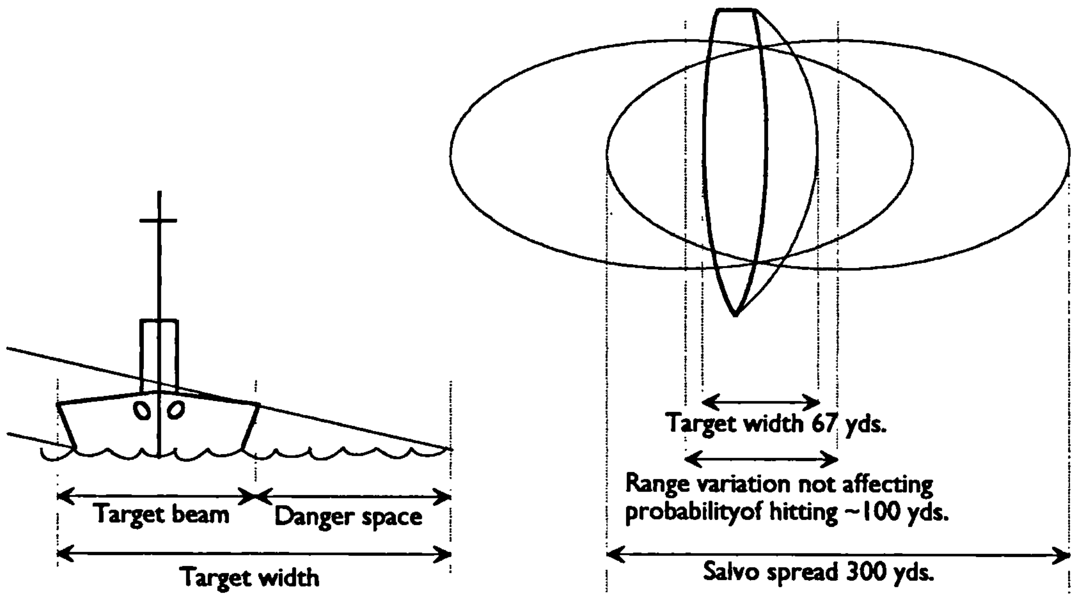
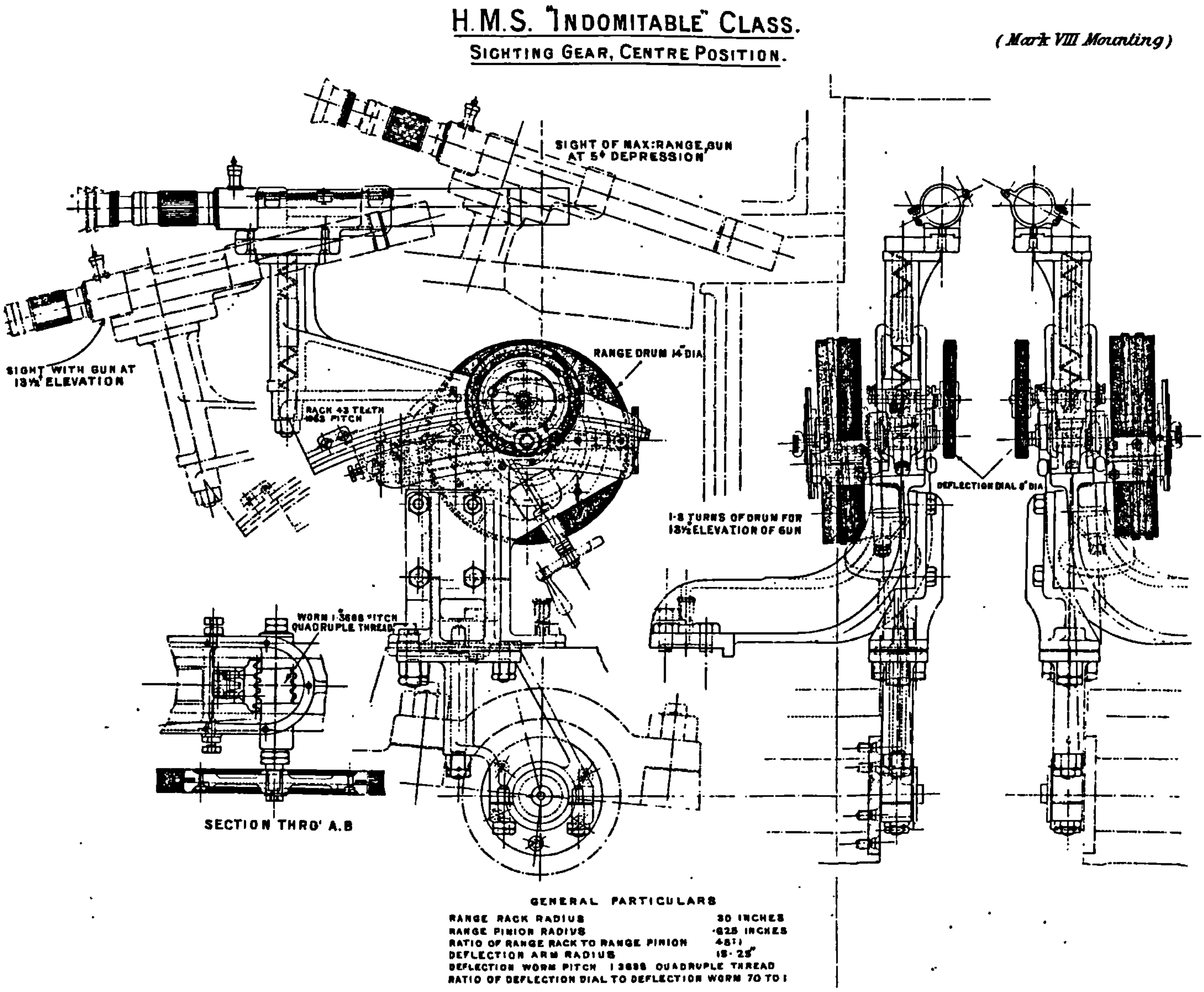


FIG. 2.13: DANGER SPACE

yards at 16,000 yards, the gun-range could vary by about 100 yards with little effect on the probability of hitting. This, not the danger space alone, provides an indication of the accuracy to which the range had to be determined.[38] In any case, there was no point in striving for accuracies better than the errors detectable by spotting. Wartime experience established that the minimum spotting correction for range should normally be 200 yards (though 100 yards was allowed if the target had already been straddled) and for rate, 100 yds/min.[39] The uncertainties in ranges and bearings, and the additional errors arising from the use of some form of plotting to obtain rates, meant that the initial errors were likely to exceed substantially these minimum corrections. Success in battle then had to rely on the skill of the control officer in reconciling the imperfectly predicted ranges and rates with what he could see of the target and the fall of his salvoes. Long range gunnery in the dreadnought era was, quite literally, a hit and miss affair.

[38] Danger space was defined as the distance *beyond* a 30 ft. high target (a typical superstructure height): *Range Tables 1918*, p.7. However, in 'The Quest for Reach' Sumida states: 'For the purposes of this paper, the plus-or-minus margin for [range] error was considered to be half the danger space' and concludes that the range tolerance at 15,000 yards was only 13 yards: Stephen Chiabotti (ed.) *Tooling for War: Military Transformation in the Industrial Age* (Chicago, 1996) pp.50 and 82.
[39] *Spotting Rules 1916*, pp.8 and 14. See also '14. Fire Control Organisation', Home Fleet General Orders, 5 November 1913, p.3, DRAX 1/9.

Plates for Chapter 2



I. Direct-action Gun Sight

To eliminate mechanical backlash, the whole sight was clamped directly on the gun trunnion. As the range-drum was rotated to set the range, the telescope elevation was altered by the action of a pinion on the curved rack.

Admiralty, Gunnery Branch, *Addenda (1909) to Gunnery Manual Vols. I (Part I) and III*, November 1909, Plate XXV[A], NMM.

Fig. 1

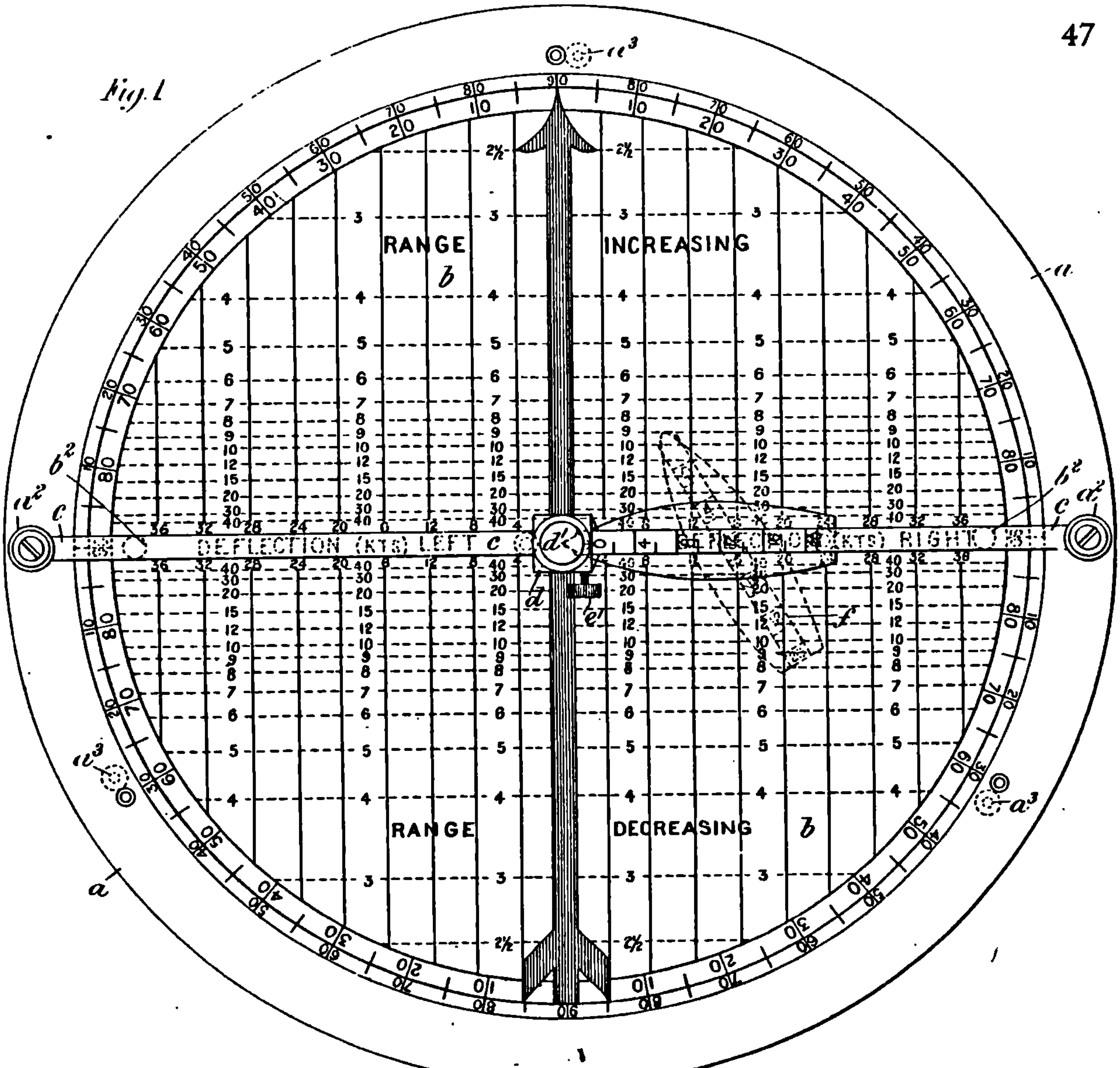
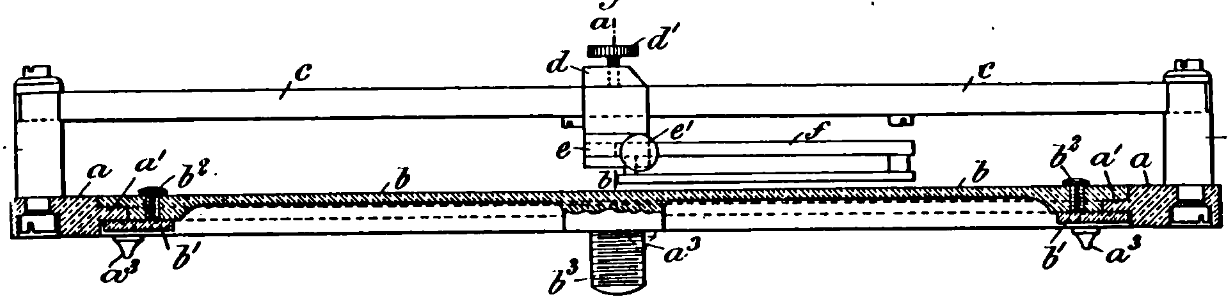


Fig. 2.



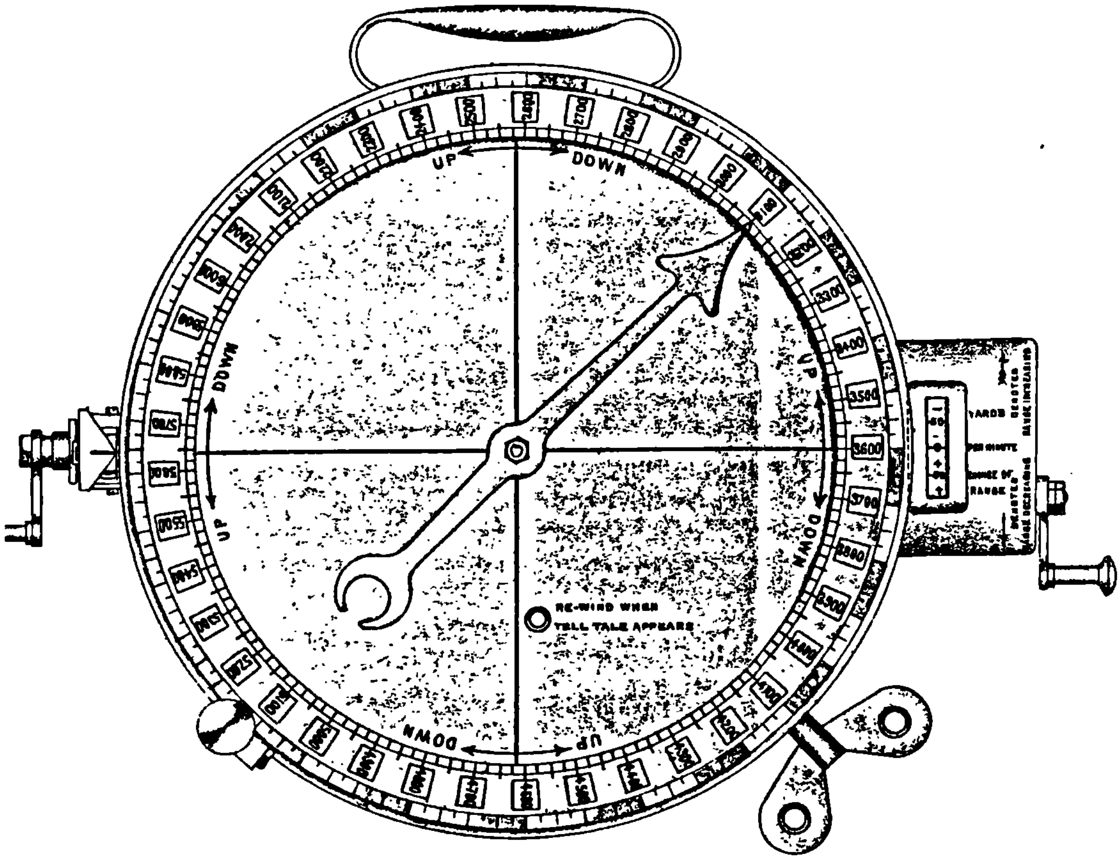
2. Dumaresq

The Dumaresq Mark I was very similar to the instrument as patented.

As shown in *Fig. 1*, the instrument is set for a target directly on the starboard beam. The enemy course is either parallel (enemy model drawn with solid lines) or diverging at about 60° (dashed lines).

The disc is graduated for deflection in knots and for range-rate in 'seconds to change 50 yards'. On later versions, range-rate was shown in yards-per-minute.

Patent 17,719/1904, application 15 August, complete 7 June 1905.



3. Vickers Clock

Inner and outer range scales were graduated in 25-yard steps. One of three sets of numerals were visible through the small windows; thus the scales could be read from 2,000-6,000: 6,000-10,000 or 10,000-14,000 yards.

Scales and numerals were rotated together with the handle shown to the left; this was used to apply spotting corrections with the aid of the outer range scale. One turn of the handle changed the range by 100 yards.

Range-rates (by 1909 expressed in yards-per-minute) were set by means of the handle and scale shown to the right.

Admiralty, Gunnery Branch, *Addenda (1909) to Gunnery Manual Vols. I (Part I) and III*, November 1909, p.54 and Plate XXXVII, NMM.

3

PROGRESS IN GUNNERY

> I suppose the years from 1904 to 1914 covered more real material progress in naval weapons and equipment than any other ten year period, before or since.[1]

At the start of this decade of progress in gunnery,[2] few ships had more than a short-base rangefinder and some sight telescopes to use in their long-range firings. By its close, the latest dreadnoughts were being fitted with Dreyer Tables and Directors. However, most of the battle-fleet depended on a simpler, manually-worked system comprising instruments which, in several cases, had their origins even before 1904. The purpose of this chapter is to examine how these devices originated and were developed by the Royal Navy and its suppliers: and thereby to establish the technical and organisational context in which the rivalry between Pollen and Dreyer was played out.

Under the Controller, the Director of Naval Ordnance and Torpedoes (customarily abbreviated to DNO) 'is generally responsible to the Board of Admiralty in regard to...the armament of the Fleet [and] all matters connected with the Ordnance and Torpedo material of the Navy'. His deputy, the Assistant Director of Torpedoes, had his own staff to deal with torpedo matters; the DNO also had a large staff concerned with the inspection of guns and mountings. However, only a few officers within his department

[1] Hugh Clausen, 'Design and the Conditions which Influence It', Notes based on two lectures to the N O D in March 1947, p.1, CLSN 3/1, CC. Clausen designed the prototype GDT gear with Lieut. J S Dove during WWI and afterwards the M-type receiver motor and the Admiralty Fire Control Clock. From 1936, he was Chief Technical Adviser to the Director of Naval Ordnance. See also Lord Chatfield, *The Navy and Defence* (London, 1942) pp.30-1.

[2] From July 1903, the *Half Yearly Summaries of Progress in Gunnery* kept the gunnery officers of the Fleet informed of the latest developments. There is an incomplete run, the earliest issue being No. 7 of July 1906, in the Admiralty Library. See also 'Institution of Half Yearly Summary of Gunnery Progress' in ADM 1/7685, PRO.

were assigned to the development of new material;[3] for example, under Captain H D Barry, DNO from October 1903 to February 1905, Commander Lynes had sole responsibility for experimental work on non-transferable mountings, sighting gear, rangefinders, firing gear and communications. The DNO and his assistants[4] could, however, call on the resources of the gunnery and torpedo schools at Portsmouth, HMS *Excellent* and HMS *Vernon*, the latter providing special expertise in all electrical matters.[5] The Captain of *Excellent* was also regarded as 'the principal Admiralty Experimental Officer',[6] a role in which he was assisted by his Experimental Commander.[7] One of their duties was to examine and report on the 'innumerable inventions' submitted to the Admiralty.[8]

An annual long range gunnery practice at 6,000 yards had been introduced in 1901[9] but, without proper instruments or training of gun crews, Percy Scott was probably justified in describing it as 'trying to run before we can walk'.[10] In April 1903, Scott was appointed Captain of *Excellent.*[11] In September, the Admiralty agreed to trials of 'the various methods of Controlling, Directing and Ranging Gun Fire in Action' then in use afloat,[12] the ships selected being *Victorious* (Channel Squadron) and *Venerable* (Mediterranean Fleet). Their *Joint Report*,[13] with some qualifications submitted by Scott,[14] established the requirements which led to the first complete set of instruments for long range gunnery: and, with one exception, these were ready for the first, experimental cruise of HMS *Dreadnought* in early 1907.

[3] They appear in the *Navy List* as 'Assistants to the DNO'.
[4] Their close working relationship is described in Frederic Dreyer, *The Sea Heritage* (London, 1955), p.57.
[5] C I Thomas, *Instructions for the Director of Naval Ordnance and Torpedoes and Assistant Director of Torpedoes*, 24 September, 1907. *Paper prepared by the Director of Naval Ordnance and Torpedoes for the Information of his Successor*, February, 1905, p.25-6. Professor Sumida has lodged a set of copies of these reports by DNOs for their successors in the Admiralty Library and the present author is most grateful for the opportunity to make his own copies.
[6] Lord Selborne to Senior Naval Lord, 12 May 1904, MS. Selborne 41, f.158, Bodleian Library, Oxford.
[7] R Travers Young, *The House that Jack Built* (Aldershot, 1955) Chapter 10.
[8] Reginald Tupper, *Reminiscences* (London, 1929) p.183.
[9] *Manual of Gunnery (Volume I) for His Majesty's Fleet 1901* (London, 1901) p.382, Ja254, AL.
[10] Percy Scott, 'Remarks on...Straight Shooting...' 28 February 1902 in *Gunnery* (lectures privately printed 1905), p.11, copy in the Craig Waller papers. The author is most grateful to Commander Michael Craig Waller for the opportunity to examine his father's papers.
[11] Peter Padfield, *Aim Straight* (London, 1966) pp.95-107.
[12] Admiralty letter 5 September 1903 in 'Communication and Control of Gunfire in Action' in ADM 1/7756. DNO's submission 7 June 1902 in '3116: Systems of Communication to Guns' in *Principal Questions dealt with by Director of Naval Ordnance, January to December 1905*, p.418, PQ16, HRO.
[13] *Joint Report of the Mediterranean and Channel Committees on Methods of controlling Gun Fire in Action*, 16 May 1904, p.12 in ADM 1/7758.
[14] Percy Scott, *Remarks of the Captain of "Excellent" on the Joint Report of the Mediterranean and Channel Committees on the Control of Fire*, 2 July 1904 in ADM 1/7758.

ARETHUSA TO *DREADNOUGHT*

RANGEFINDERS

Following the developments in gun materials, construction, propellants and mountings made in the later 1880s,[15] the Admiralty took the first step towards increasing the range at sea by issuing a requirement for a rangefinder accurate to 3% at 3,000 yards.[16] In comparative trials in HMS *Arethusa* in April 1892, the Barr and Stroud coincidence rangefinder, which had been designed in 1888, proved superior. With orders in hand from the British and foreign navies, the two professors were able to establish their company in Glasgow; 'by March 1898 the firm had sold over 150 of their rangefinders around the world'.[17]

The *Manual of Gunnery 1901* confirms that Barr and Stroud instruments, mainly the improved Mark II, otherwise FA2, were then in full service,[18] though they were inadequate at long range[19] and, since 1899, the Admiralty had been attempting to procure a more accurate rangefinder.[20] In 1903, Barr and Stroud introduced a new model, the FA3, with nearly twice the previous accuracy; the *Joint Reports* of both Committees recommended that it could 'be usefully employed up to even 8,000 yards', particularly if given finer graduations, 'but for the longer ranges...it is necessary that an even better one should be obtained'.[21] In 1904, the Admiralty decided to advertise again;[22] the products of several suppliers, including Barr and Stroud, were being considered in 1905[23] and, by July 1906 'satisfactory trials have been carried out with a rangefinder produced by Barr and

[15] Peter Padfield, *Guns at Sea* (London, 1971) pp. 194-7. Ian Hogg and John Batchelor, *Naval Guns* (Poole, 1978) pp.93-101. Iain McCallum, 'Achilles Heel? Propellants and High Explosives, 1880-1916' in *War Studies Journal*, Volume 4, Issue 1, Summer 1999, pp. 65-9.
[16] Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) p.72.
[17] Michael Moss and Iain Russell, *Range and Vision* (Edinburgh, 1988) pp.24-32.
[18] *Manual of Gunnery (Volume I) for His Majesty's Fleet 1901* (London, 1901) p.138.
[19] 'Schemes of Communication', n.d. but 1903, f.10 in 'Communication and Control' *(op. cit.)*. Admiralty, Gunnery Branch, *Interim Report of the Mediterranean Committee on the Control of Fire, &c*, forwarded 18 February 1904, pp.20 and 21 in ADM 1/7756.
[20] 'We have been now for the last five years been trying to get a more accurate rangefinder'. Admiral W H May (Controller), 13 July 1904 in 'Report of Committees on Control of Fire' in ADM 1/7758.
[21] *Joint Report of the Mediterranean and Channel Committees relative to the System of Firing and Allocation of Ammunition*, 30 May 1904, p.2 in ADM 1/7759. *Joint Report...controlling Gun Fire* (*op. cit.*) p.12. From 6-10,000 yards, the Mark III was graduated in 500 yard steps.
[22] F C Dreyer and C V Usborne, *Pollen Aim Corrector System. Part I: Technical History and Comparison with Commander F.C.Dreyer's Fire Control System*, February 1913, p.4, P. 1024, AL.
[23] *DNO for Successor* (*op. cit.*) February 1905, p.14. The other suppliers were Dunlop & Grubb, Stevenson and Lawrence & Capper.

Stroud having a 9-foot base...'.[24] Sufficient were ordered to fit two of these instruments (designated FQ2) in the latest all-big-gun ships.[25] The new instrument further secured Barr and Stroud's position as, in effect, the monopoly supplier; at £325, the FQ2 was not inexpensive, but the firm refused to compromise on quality or price.[26]

GUN SIGHTS

On 4 May 1898 (just over a year before the famous prize-firing by *Scylla*, Captain Percy Scott),[27] the Ordnance Committee decided to seek the advice of Dr A A Common FRS, a Past President of the Royal Astronomical Society and an eminent optician, on the best form of telescope for use with automatic sights. From 1900 onwards, telescopes were purchased in quantity,[28] either through Common or direct from manufacturers, including Barr and Stroud.[29] Initially, priority was given to fitting the more mobile hand-worked guns before turret guns but, by the end of 1903, the supply of 'one [telescopic sight] per gun, 12-pr. and above, is now nearly complete...' while 'Money has been provided in the 1904-05 Estimates for...the supply, to all existing 6-inch guns, of a second telescope (the variable power [by Ross])'.[30]

Unfortunately, fitting telescopes to old mountings only served to emphasise the mechanical imperfections of their indirect sights.[31] After the introduction of a semi-direct type for the *King Edward VII* class, a new direct-action sight was designed for the paired 9.2-inch and 12-inch turrets of the *Lord Nelson* class; since it was mounted directly on the trunnions, backlash due to mechanical linkages was eliminated.[32] In reality, the first five of

[24] Admiralty, Gunnery Branch, *Half Yearly Summary of Progress in Gunnery, No.7, July 1906*, p.15, Ja 238, AL.
[25] *SPG* (*op. cit.*) *January 1907*, p.23. *DNO for Successor*, July 1907, p.26.
[26] *Range and Vision* (*op. cit.*) pp.39, 44 and 54-6.
[27] Percy Scott, *Fifty Years in the Royal Navy* (London, 1919) p.88. These memoirs must be treated sceptically: John Brooks, 'Percy Scott and the Director' in David McLean and Antony Preston (eds.) *Warship 1996* (London, 1996) pp.151-2 and 167-70.
[28] Report by Lt. Craig and DNO to Captain of *Excellent*, 30 November 1900 in 'New Pattern Telescopic Sight for Barbette and Turret Guns' in ADM 1/7686.
[29] 'Proceedings of the Ordnance Council...26th February 1903' in *Ordnance Council Cases 1901-1902-1903* in ADM 1/8222. An award of £1,000 to Dr Common was recommended in connection with the use of his patents. At £4/11/10, Barr and Stroud's was the lowest price.
[30] Admiralty, Gunnery Branch, *Manual of Gunnery for His Majesty's Ships Vol. I, 1901, Addenda (1902)*, December 1902, p.26, Ja 254, AL: *DNO for Successor*, December, 1903, p.14. For the build-up in expenditure on sights, see Jon Sumida, 'The Quest for Reach' in Lt. Col. S D Chiabotti (ed.) *Tooling for War: Military Transformation in the Industrial Age* (Chicago, 1996) p.56 and footnote 24.
[31] *Joint Report...Allocation of Ammunition* and Scott, *Fifty Years*, pp.182-5. For delays to resighting older ships caused by Scott's interference, see Brooks, 'Scott and the Director', p.152. (All *op. cit.*)
[32] *DNO for Successor*, February 1905. p.15.

the B.VIII mountings were installed in *Dreadnought*,[33] which was therefore the first ship afloat with this new type of precision telescopic sight (Plate 1).

More accurate sights warranted precise calibration for the individual characteristics of each gun. An allowance of ammunition for calibration had been authorised in October 1904 but, once again, Scott considered this premature. In 1905, as soon as a ship with accurate sights was available (*Commonwealth* of the *King Edward VII* class), a Calibration Committee was appointed, with Scott, now Inspector of Traget Practice (ITP) as President. In August 1905, their recommendations were promulgated to the Fleet[34] and, by 1907, six calibration ranges had been established world-wide.[35]

ELECTRICAL FIRE CONTROL INSTRUMENTS

While the Royal Navy was still dependent on voice-pipes for the communication of range and orders, in 1894 Barr and Stroud began the development of electrical instruments for this purpose. Their first customer was the Imperial Japanese Navy in 1898, the Royal Navy ordering their first set a year later.[36] Further sets were purchased for the experiments in *Venerable* and *Victorious*,[37] but the *Joint Report* described them as 'somewhat complicated and cumbersome'; it also recommended that the instruments of other manufacturers should be tried and that, in future, ranges should be displayed 'as on a cyclometer' rather than on circular dials.[38] Barr and Stroud had already submitted proposals for a double-dial range instrument which could transmit ranges in 25-yard steps up to 12,000 yards.[39] For the moment, this improvement was enough to retain the Admiralty's custom; in February 1905, the outgoing DNO reported that Barr and Stroud range and order instruments were being bought as quickly as possible and, eventually, fifteen ships were fitted.[40] However, they were judged 'clumsy and not all we would

[33] Peter Hodges, *The Big Gun* (London, 1981) p.51. John Roberts, *The Battleship Dreadnought* (London, 1992) p.28.
[34] Captain of *Excellent* to DNO, 7 March 1903, Scott to DNO, 17 October 1904, etc. in 'Calibration of Guns. Report of Committee &c' in ADM 1/7835. Compare with the later account in Scott, *Fifty Years*, pp.180-1.
[35] *DNO for Successor*, July 1907, p.26.
[36] *Range and Vision*, pp.34-5. 'Schemes of Communication' (*op. cit.*) p.10.
[37] Controller to Admiral Superintendent, Chatham, 25 October 1903 in 'Communications and Control'. *Mediterranean Interim Report* (*op. cit.*) p.5.
[38] *Joint Report...controlling Gunfire*, pp.11-12.
[39] Correspondence in 'Barr and Stroud electrical Transmitters and Receivers...1903-04' in ADM 1/7760. Admiralty, Gunnery Branch, *Handbook for Fire Control Instruments 1906*, pp.8-10 in PLLN 1/8, CC.
[40] *DNO for Successor*, July 1907, p.18.

wish',[41] probably because, although on the step-by-step principle (which required only a few wires between transmitter and receiver), the instruments relied on spring-powered clockwork and an electrically-operated escapement.

Barr and Stroud were not, however, without rivals. Even in 1902, the Admiralty were considering fire control instruments from Messrs. Cory of New York (as fitted in the *Illinois*), Eversheds and a design by Captain Grenfell.[42] By February 1905, *Vernon* had tried types by Elliott Brothers, Watkin, Thorp, Chatham E.E. and others, though none had proved satisfactory. Siemens Brothers were offering direct-working (synchronous) instruments[43] invented by a Mr Grimstone but, despite promising early trials, a different design from the German Siemens-Halské firm was selected subsequently for use in nineteen pre-dreadnoughts.[44] Meanwhile, in early 1905, trials were beginning of a new step-by-step instruments submitted by Vickers, though the design was strongly influenced by Percy Scott.[45] The electric pulses from the transmitter alone powered the receiver motor, while its rotor could take up only four stable positions.[46] This technical advance enabled Vickers to supplant Barr and Stroud and, eventually, 42 ships had complete Vickers installations; an installation for HMS *Illustrious* (*Majestic* class) cost £1,242. The list was headed by *Dreadnought* herself.[47]

THE DUMARESQ

Lieutenant John Dumaresq may have invented his instrument in 1902[48] but he was still developing it in May 1904, after it had been tried by the fire control committee in

[41] *DNO for Successor*, February 1905, p.19.
[42] Minutes by the Controller 1 August and DNO 18 September 1902 in *Principal Questions by DNO 1905* (*op. cit.*) pp.418-9. For Grenfell's instruments, see also 'Schemes of Communication', p.9.
[43] Synchronous instruments, unlike the step-by-step type, could not get out of step but they required many more wires between transmitter and receiver.
[44] W H May, 13 July 1904 (*op. cit.*). 'Report on Range and Order Telegraphs and on Sight Moving Gear', 12 August 1904 in 'Barr and Stroud's Transmitters and Receivers' (*op. cit.*). *DNO for Successor*, February 1905 p.19, July 1907 p.18 and November 1909 pp.14 and 19. Admiralty, Gunnery Branch, *Handbook of Fire Control Instruments, 1914*, pp.11-3, NMM and ADM 186/191.
[45] Scott, 'Gunnery Lecture No. IV', 28 February 1905 in *Gunnery* (*op. cit.*) p.53. *Principal Questions by DNO 1905*, p.460. For Scott's royalties on these instruments, see Brooks, 'Scott and the Director', p.152.
[46] *Fire Control Instruments 1906* (*op. cit.*) p.19.
[47] *Principal Questions dealt with by Director of Naval Ordnance January to December 1906*, p.749, PQ 16, HRO. *DNO for Successor*, November 1909, pp.14 and 17. The Vickers installation comprised range, order and deflection instruments. For the *Dreadnought* installation, see Captain R H Bacon, *Report on Experimental Cruise*, March 1907, pp.27, 83, 85, 101, 103 and App. HG V, ADM 116/1059.
[48] 'Recommendation of the Royal Commission on Awards to Inventors', 30 October 1925 reproduced in Anthony Pollen, *The Great Gunnery Scandal* (London, 1980) p.252.

his own ship, the *Victorious*.[49] Although two other 'Rate of Change' instruments were mentioned by the Mediterranean Committee,[50] the *Joint Report* recommended the adoption only of the Dumaresq, for control tops, turrets and 6-inch groups, noting specifically that it 'combines rate of change and deflection'.[51] The first Service model Dumaresq (Plate 2 - later known as the Mark I) was graduated for deflection in knots but the range rate was expressed in seconds to change 50 yards,[52] the most convenient units while the range was kept only with the aid of a stop-watch.[53] This and later models were manufactured by Elliott Brothers, who paid the fees when the device was patented (though in Dumaresq's name) in August, 1904.[54] This marks an early success for a firm which was later to supply many more of the Royal Navy's fire control instruments.

By mid-1906, 'a design is also being got out of an instrument of greater size'[55] though this was not, apparently, ready in time for *Dreadnought*'s first experimental cruise.[56] By mid-1907, 'from two to six of these instruments are supplied to electrical fire control ships...half being of the large Mark II size and half small Mark I'.[57]

SCOTT/VICKERS CLOCK

In a lecture delivered in December 1903, Percy Scott gave the first description of a range clock comprising an indicator hand moving round a circular range scale at a rate which could be continuously adjusted (Plate 4); the range scale could be rotated to set the initial range and to apply spotting corrections.[58] In April 1904, Scott's associates at Vickers applied for a patent which described a number of alternative designs, all based on variable speed drives, including the disc-and-roller eventually adopted.[59] Despite Scott's hopes,[60] no clock had been completed for trial by the committees on fire control, though

[49] 'Draft Report of the Channel Fleet Fire Control Committee', 21 April 1904, p.4 in 'Report of Committees on Control of Fire' in ADM 1/7758.
[50] *Mediterranean Interim Report*, p.16.
[51] *Joint Report...controlling Gunfire*, p.11. At the time, Dumaresq was serving aboard HMS *Victorious*.
[52] *SPG, July 1906*, p.23 states that a description was promulgated in the summary for July, 1904. A patent (17,719) was applied for on 15 August 1904.
[53] *Joint Report*, p.11. Admiralty, Gunnery Branch, *Fire Control. A Summary of the Present Position of the Subject*, October 1904, p.8 in ADM 1/7760.
[54] G K B Elphinstone, 'Dumaresq Designs & Patents. Notes as to History', January 1916 in 'Fire Control Apparatus, Various Patents', ADM 1/8464/181. Patent 17,719 of 1904, applied for 15 August 1904.
[55] *SPG, July 1906*, p.23.
[56] *Experimental Cruise* (*op. cit.*) pp. 28 and 95.
[57] *DNO for Successor*, July 1907, p.20.
[58] Scott, 'Remarks on Long Range Hitting', 15 December 1903 in *Gunnery*, p.27 and Plate II.
[59] Patent 9461 of 1904 applied for 25 April 1904, complete (with figures) 24 February 1905 though without any details of the clockwork drive.
[60] Scott to Jellicoe (Captain of *Drake*) 2 January 1904 in 'Report of Committees...' in ADM 1/7758.

the Channel Committee still recommended his proposal rather than an earlier design by Lieutenant Fawcet Wray.[61] The first Scott/Vickers clock was probably completed in 1905 while, by mid-1906, delivery was awaited of the first, large production order of 246.[62] On her experimental cruise, *Dreadnought* had several (probably three) Vickers clocks in her transmitting station, sufficient to allow some of her turrets to be controlled independently if required.[63]

Of the Dumaresq, Scott remarked:

> I do not think that machines to calculate the rate of change in distance will be of much use, their working must depend upon what you estimate the relative speeds and courses to be.

Instead, he proposed that the range rate should be 'obtained by Range Finding and timing, or guessed';[64] by 1906, finding the rate by timing was accepted as one 'of the two principal methods of ascertaining and keeping the rate',[65] though, at long range with 4½-foot rangefinders, it was considered no more accurate than using a Dumaresq with estimated enemy speed and course. Scott also suggested that: 'If the fall of shot shows that too much or too little change in range is being applied, the rate can be altered';[66] this is the first mention of what was later called rate spotting: but Scott did not say how the rate might be altered, any more than he explained how to obtain an opening deflection without a Dumaresq. Scott concurred with the view in *Venerable's* interim report that the contemporary 4½-foot rangefinders could give an approximate indication of the opening range, but that the target could only be found by spotting.[67]

[61] 'Channel Draft Report' (*op. cit.*) p.6. Report by Lieut. A V Vyvyan in R A Burt, *British Battleships 1889-1904* (London, 1988) p.45-51. The writer is indebted to Professor Sumida for this reference.
[62] *SPG, July 1906*, p.22. The clock is not mentioned in *DNO for Successor*, February 1905. 'Quest for Reach' (*op. cit.*) p.11, citing Scott's lecture, states that the first clocks had been tested by the end of 1903.
[63] *Progress in Gunnery, January 1907*, p.31. *Experimental Cruise*, pp.83 and 101.
[64] Scott, 'Long Range Hitting', pp. 27-8.
[65] *SPG, July 1906*, pp.39 and 42. See also 'Memorandum by Director of Naval Ordnance on Towing Targets' in *Navy Estimates Committee. Report upon Navy Estomates for 1908-9*, Admiralty, November 1907, FISR 8/11, CC.
[66] Scott, 'Long Range Hitting' (*op. cit.*) p.27.
[67] *Mediterranean Interim Report*, p.22. Scott, *Remarks on the Joint Report* (*op. cit.*) pp.2 and 12. For the necessity to spot shorts, see Scott, 'Lecture IV' (*op. cit.*) p.51. Scott's reservations about contemporary rangefinders and the Dumaresq (the latter set by estimation and used with a stop-watch to keep the range) seem insufficient grounds for Sumida's view ('Quest for Reach', pp.10-11) that opinion was polarised into 'spotting and instrument factions'.

DREADNOUGHT

By 1906, the supply of almost all the fire control instruments for *Dreadnought* had been arranged. However, after successful experiments aboard *Duke of Edinburgh*, it was decided that, in future, the clocks and the range and deflection transmitters to the individual turrets should be moved below to a Transmitting Station (TS), protected by armour, near the base of each mast. The TS would be connected by a large diameter voice pipe to its top, where the rangefinder and Dumaresq remained, 'the initial range and spotting corrections and deflection being passed by voice pipes and the "rate" by special electrical transmitters'.[68] On her experimental cruise *Dreadnought* was fitted with an improvised TS above the armoured deck; also, she had to rely only on voice pipe communication from the top, the new range-rate instruments not being yet available. But, with this one exception, *Dreadnought* was fitted with all the new fire control instruments which had been developed in the preceding years.

Despite her many novelties, in one respect *Dreadnought* was no different from her predecessors. In October 1906, the report on *Dreadnought's* gun trials noted that 'it is extremely difficult to readily obtain a slow movement of the guns in elevation which is required to follow the small roll or to keep the sights on at the bottom or top of a larger roll', while the training gear was 'not good enough to keep the sights continuously on for fire at a moving object when the ship is under way'.[69] Thus the continuous aim necessary for salvo firing was impossible with any motion on the ship. Even in the calm conditions of the Experimental Cruise, on two runs *Dreadnought* ranged with a single gun and fired a single salvo: but then, presumably due to induced roll, followed after more than a minute with a four-gun ripple.[70]

[68] *SPG, January 1907*, pp. 26-8.
[69] 'Report of Gun Trials' 23 October 1906, Ship's Cover 213A/82, *Dreadnought*, NMM.
[70] *Experimental Cruise*, pp.96-9. The intervals between the salvoes and the first rounds of the subsequent ripples were 65 and 63 secs., respectively. The duration of the ripples were 16 and 12 secs. In *The Sea Heritage* (*op. cit.*) p.57, Frederic Dreyer claimed that the guns could be reloaded every 30 secs. (the reported average was 33 secs.) and that salvoes could be fired every 15 seconds, but the latter figure is not substantiated by the report on the cruise or any other known source.

INDOMITABLE TO THE *INDEFATIGABLES*

LAYING AND TRAINING

Even before *Dreadnought* had been laid down, Captain John Jellicoe, DNO since February 1905, fully appreciated that effective fire control for the new ships depended on salvo firing[71] and he had already initiated a programme to improve the hydraulic elevating and training gear, so that turret guns could be aimed continuously.[72] While the *Manual of Gunnery 1907* (written, of course, for a pre-dreadnought fleet) admitted that 'no facilities exist at present for keeping "continuous aim" with turret guns',[73] in July1907, Jellicoe was able to report to his successor, Captain Reginald Bacon, that experiments by *Excellent* had established that:

> ...with suitably shaped elevating [valve] ports, worked by wheel elevation gear, it is possible to "hunt the roll" with hydraulically controlled mountings to the same extent as is at present possible with hand-worked mountings.[74]

Fisher was able to claim 'a tremendous improvement...in the controlling apparatus for power-worked guns' and to announce that 'Provision has been made in the 1908-09 Estimates to fit this gear to all the hydraulic turrets in the Service'.[75] Development continued[76] and, by May 1912, the outgoing DNO could report that 'it is arranged for 1911-12 ships [*Iron Duke* class and *Tiger*] to have a speed of elevating of 5° per second with one turn of handwheel'.[77]

Continuous aim also depended on continuous training of the whole turret. *Dreadnought's* turrets were trained by a pair of 3-cylinder hydraulic engines.[78] These engines were controlled by a lever-operated reversing valve and a separate 'creep-valve', worked by a wheel; this proved 'very awkward' in use, making 'continuous laying for fire

[71] 'Admiral Scott's proposals for "Dreadnought"', 17 August 1905 in 'Director for Turret Firing' in ADM 1/7955. Brooks, 'Scott and the Director', p.155.
[72] Correspondence between the Admiralty and Vickers, July to December 1905 in 'Dreadnought and Lord Nelson & Minotaur Class. Fitting of Single Lever gear and Creep valves to 12" and 9.2" Mountings' in ADM 1/7896.
[73] *Manual of Gunnery Vol.III for His Majesty's Fleet 1907*, p.37, Ja254, AL.
[74] *DNO for Successor*, July 1907, p.15. *SPG July 1907*, p.10 and *January 1908*, p.6.
[75] *The One Calibre Big Gun Armament for Ships*, printed June 1908, pp.11-12, ADM 1/7898 and FISR 8/31: confirmed by *DNO for Successor*, November 1909, p.7. See further John Brooks, 'All-Big-Guns: Fire Control and Capital Ship Design 1903-1909' in *War Studies Journal*, Vol.1, Iss.2, pp.36-52.
[76] *DNO for Successor*, November 1909, p.11. *SPG 1910*, p.5 and *1911*, p.6.
[77] *DNO for Successor*, May 1912, p.8.
[78] Roberts, *Dreadnought* (*op. cit.*) pp.218-221 and 225.

almost impossible except under very favourable conditions'.[79] Eventually, Portsmouth Dockyard designed a satisfactory training control in which a single wheel operated both the reversing and creep valves; by November 1909, both *Dreadnought* and *Inflexible* (the latter having the same training arrangements) had been refitted with wheel training gear on these lines.[80]

To obtain more even training torque, in 1906 Elswick (EOC) developed a 6-cylinder rotary engine, which was first installed in HIJMS *Kashima*. For British ships, Portsmouth again worked out a design for a control valve operated by a single wheel. The new control and engine, the latter rotating the turrets through a worm drive, was adopted for the battlecruiser *Indomitable*, the *Bellerophon* class and later ships.[81] During gun trials in 1908, the new gear in *Indomitable* showed a marked reduction in throw-off and good control of starting, stopping and creep with little effort on the handwheel; whereas, with *Inflexible's* Vickers turrets, which retained the older 3-cylinder training engines: 'a marked feature...was the poor training control. The creep...is jerky: the turrets do not start or stop with precision [and] the reversal of direction is erratic'.[82] A further improvement in ' "sweetness" of control' of training was obtained with the introduction (again by Elswick) of the swash-plate engine,[83] 7-cylinder engines of this type being adopted for the turrets of *Hercules*, *Colossus* and later classes.[84]

Thus, by 1912, the guns mobility was transformed, so that that:

> ...in "Orion" all gunlayers [are] able to follow a roll of 12 degrees out to out without difficulty and some a roll of 16 degrees to 18 degrees out to out.[85]

FIRE CONTROL INSTRUMENTS AND GUNSIGHTS

By mid-1907, Barr and Stroud had recaptured the lead in fire control instruments; compared with the Vickers instruments in *Dreadnought*, their Mark II

[79] Commander A W Craig, 'Hydraulic Training Gear', H.M.S. "Excellent", 23 December 1907, para.20. This report is the principal source for this section. The author is indebted to Commander Michael Craig Waller for a copy of this report, written while his father was Experimental Commander in *Excellent*.
[80] *SPG, January 1909*, p.11 and *DNO for Successor*, November 1909, pp.7-8.
[81] Craig, *Hydraulic Training Gear* (*op. cit.*) paras. 31F and 35. DNO's Minute 13 March 1906 in Ships' Cover 222, *Bellerophon* Class.
[82] 'Reports of Gun Trials of HMS *Indomitable* 23 April 1908 and HMS *Inflexible* 18 June 1908' in Ships' Cover 215A/51 and 52, *Invincible* class.
[83] *SPG, July 1909*, pp.27-29 for the experimental 10-cylinder engine in *Superb*.
[84] *DNO for Successor*, November 1909, p.11. Hodges, *Big Gun* (*op. cit.*) pp.54 and 62.
[85] Captain A. Craig, 'Rough Weather Test Firing, HMS Orion', 15 November 1912 in Craig Waller Papers. 'The term "continuous laying" is used in the sense that the sights are kept approximately laid and can be brought exactly on by a small movement when about to fire.'

instruments were judged to be better electrically than and generally very satisfactory.[86] They were chosen for the *Invincible* class and a later variant, the Mark II*, for the *Bellerophon* and *St. Vincent* classes: while, by the end of 1909, the unsatisfactory Mark I range and order instruments were being replaced by Mark IIs, a process which had been completed by 1912.[87] However, Vickers fortunes would soon revive and *Neptune* was the last dreadnought to be equipped entirely by Barr and Stroud.

In the transmitting stations of the first dreadnoughts, a clock operator would 'call the 25s and also call the range every time a full hundred yards is reached': while the transmitter men (one per turret) would rotate the transmitter handles at each 25 yard step. At the guns, the sight-setters then had to read the ranges and deflections off the receivers and set the sights accordingly. It must have been difficult to keep up when the range-rate was high; for example, if the rate was 600 yds/min., the range changed by 25 yards every 2½ seconds.[88] Some help could be provided in the TS by connecting the multiple transmitters mechanically; this was first tried in 1908,[89] after which this 'cross-connecting gear' (Plate 5) was widely fitted in pre-dreadnoughts and in dreadnoughts up to *Neptune*.[90] However, the greater problem was at the guns, as had been recognised since 1904. Two proposals were then under consideration for setting sights automatically with ranges and deflections transmitted from the TS. The first was due to Lieutenant A V Vyvyan and Mr L Newitt, Electrical Engineer at Chatham Dockyard; the second was initially from Siemens Brothers, though, encouraged by the Admiralty, they soon reached a collaborative agreement with Vickers.[91] Unfortunately, despite several years effort, neither group was successful;[92] by mid-1907, a Siemens-Vickers electrically set sight had been tried but rejected and the Vyvyan-Newitt sight was also about to be abandoned.[93]

[86] *DNO for Successor*, July 1907, p.21. The Barr and Stroud did not use a commutator in the receiver: Admiralty, Gunnery Branch, *Handbook of Fire Control Instruments 1909*, p.23, Ja345a, AL. Patent 4422/1906.
[87] *DNO for Successor*, November 1909, pp.14 and 17 and May 1912, p.14.
[88] Errors in sight ranges of 50 yards were common: Staff of Inspector of Target Practice, 'Battle Practice, 1909', Lecture 1, f.7, MS 19, *Excellent* Historical Library, copy courtesy of Prof. Sumida.
[89] *Experimental Cruise*, pp. 83-4. Admiralty, Gunnery Branch, *Fire Control*, 1908, pp.32-3, 45, 49 and Enclosure XV in ADM 1/8010 and T.173/91 Part I.
[90] *Fire Control Instruments, 1909* (*op. cit.*) p.34 and Plates 46 and 47. Cross connection gear was supplied by both Barr & Stroud and Vickers for use with their respective instruments.
[91] DNC's minute 'Report on Range and Order Telegraphs and on Sight Moving Gear', 12 August 1904 in 'Barr and Stroud's Transmitters and Receivers'. Correspondence and reports in 'Vyvyan-Newitt, Siemens & Vickers Electrically Controlled Gun Sights' in ADM 1/7832. For later recognition of Vyvyan's and Newitt's work, see Viscount Hyde (ed.), *The Naval Annual 1913* (reprinted Newton Abbot, 1970) pp.322-3.
[92] *SPG, January 1907*, p.17 for Vyvyan-Newitt.
[93] *DNOs for Successors*, February 1905, p.19 and July 1907, p.22. See also *Fire Control*, 1908 (*op. cit.*) p.5.

However, Vickers had already submitted a simpler alternative in conjunction with the new cam-sights on the Vickers P. II 4-inch mountings for the light cruiser *Boadicea*.[94] This was the follow-the-pointer sight, which still used the sight-setter's muscle power to set the sight, but required him only to keep a pointer (driven by a new brushless step-by-step receiver motor connected to a transmitter in the TS) continuously aligned with an index-marker.[95]

In dreadnoughts, periscopic sights, in which the sight elevation was controlled by a cam and roller (rather than the previous curved rack with pinion), were introduced for the *St. Vincent* class.[96] Then, for *Hercules*, *Colossus* and *Indefatigable*, the sights were fitted with Vickers follow-the-pointer gear, an arrangement (Plate 6) which became the standard thereafter;[97] by 1916, it was considered that:

> The outstanding improvements of the whole [pre-War] period are the introduction of the cam system and its adaptation to "follow-the-pointer".[98]

The technology of the follow-the-pointer sights was also essential to the development of the Director, of which Vickers commenced production deliveries in 1913.[99] That year marked the beginning of a monopoly in the supply of devices on the circuits to the guns which the firm still held even after World War II.[100] However, Barr and Stroud continued to supply the instruments for communicating all other ranges, rates, bearings and orders.[101]

TARGET BEARINGS

Following tactical exercises by the Home Fleet in early 1910, the C.-in-C., Admiral Sir William May, requested action on the 'very general desire...for some accurate and reliable means of pointing out at the gun positions the ship to be attacked'.[102] As a

[94] *DNO for Successor*, July 1907 pp.22 and 24.
[95] Vickers, Sons and Maxim Ltd., *Fire Control System 1910. The Vickers Mark III Follow-the-Pointer Instruments*, p.3, Ja 391, AL
[96] *DNO for Successor*, November 1909, pp.9, 14 and 18.
[97] *DNO for Successor*, May 1912 p.14. *Fire Control Instruments 1914* (*op. cit.*) pp.18 and 72. Admiralty, Gunnery Branch, *The Sight Manual 1916*, pp.6-7, ADM 186/216. Sights were normally designed with the mountings: *DNO for Successor*, July 1907, p.25.
[98] *Sight Manual 1916* (*op. cit.*) p.4.
[99] The development and use of the Director is fully described in Brooks, 'Scott and the Director'. For the positions of Director sights, see John Brooks, 'The Mast and Funnel Question: Fire-control positions in British Dreadnoughts, 1905-1915' in John Roberts (ed.), *Warship 1995* (London, 1995) pp.40-60.
[100] J D Scott, *Vickers, A History* (London, 1962) pp. 115, 166, 220 and 354.
[101] *Fire Control Instruments 1914* (*op. cit.*) p. 72 and diagrams of the fire control instruments in *St. Vincent* (plates 65 and 66), *Orion* and *Iron Duke* (plates 68 and 69).
[102] May to the Secretary of the Admiralty, 25 April 1910 (H.F.No.802/071) in 'Gunnery: Effects

result of Admiral Wilson's recommendations after the *Ariadne* trials, instruments for the transmission of target compass bearings (designated Mark I) had been obtained from Barr and Stroud.[103] These were soon superseded by the Mark II, which indicated relative bearings to port or starboard. Both designs, of the usual step-by-step cyclometer type, indicated in steps of ¼°.[104]

A new type of bearing instrument, based on a different method of transmission, was under consideration even in 1908.[105] In 1907, the firm of Evershed and Vignolles had submitted range, order and deflection instruments working on the balanced-bridge principle, which the firm had used previously in helm indicators. Although judged too large and expensive for their original purpose,[106] the technology proved adaptable to target bearing indication; the first prototype Evershed installation was ready in January 1910 for trials aboard HMS *Superb*:[107] though supply of the more elaborate production version did not commence until December 1912, with *Bellerophon*.[108]

The Evershed transmitter was coupled to an optical target indicator, which could be a telescope, periscope (Plate 7) or the gyro-stabilised Argo rangefinder mounting. One form of receiver (Plate 8) was mounted on the telescope of the turret trainer's sight; it indicated directly the direction in which the turret must train to bring the designated target into the field of view of the sight telescopes.[109] By the outbreak of war, all the 12-inch battleships and battlecruisers had been supplied, except for *Neptune*, *Australia* and *New Zealand*: although, of the 13.5-inch ships, only *Lion* and *Princess Royal*, *Orion*, *King George V* and *Centurion* had been fitted. After the start of the war, priority was given to 15-inch ships as they were completed, so (with the exception of *Conqueror* in February, 1915) no more installations were made in the earlier ships until after Jutland.[110] Ships without

on...plotting...etc. of new developments in Fleet Tactics' in ADM 1/8051.

[103] *Fire Control*, 1908, p.4. DNO's minute, 27 May 1908 in ' Experiments in "Vengeance". Report of Admiral Wilson' (*op. cit.*).

[104] *Fire Control Instruments 1909*, p.32.

[105] Dreyer to Hughes-Onslow, 19 October 1908 in T.173/91 Part VII.

[106] Hugh Clausen, 'Invention and the Navy - the progress from Ideas to Ironmongery' in *The Inventor*, Vol. 10, No. 1, March 1970, CLSN 3/7. *DNO for Successor*, July 1907, p.21.

[107] *DNO for Successor*, November 1909. At that date, the trial installation was intended for *Dreadnought*.

[108] 'Details of Bearing Indicators, Main Armament' in 'Gunnery Information derived from or confirmed by the action of 31st May 1916, Report of Dreadnought Battlefleet Committee', June 1916, ADM 1/8460/149. Minute from DNO received 4 May 1910, in 'Gunnery: Effect...of new developments' (*op. cit.*).

[109] *Fire Control Instruments 1914*, pp. 30-42.

[110] 'Bearing Plates...in Night Control Positions', 25 June 1914 in 'Important Questions dealt with by DNO', Copies, precis, &c. Volume III, 1914, p.633, AL. 'Bearing Indicators, Main Armament' (*op. cit.*)

Eversheds or Directors had to rely on Barr and Stroud Mark II bearing receivers to keep all turrets on the same target.[111]

RANGEFINDERS AND MOUNTINGS

As first mounted in *Dreadnought*, the 9-foot rangefinder was elevated and trained by the one operator who also took the ranges.[112] By the end of 1909, improved mountings with separate training gear - the rangetaker remained responsible for elevation - were on order for the *St. Vincent* and later classes, together with conversion kits for existing ships.[113] By early 1912, deliveries had begun of the Argo gyro-stabilised rangefinder mounting.[114] In the *Lion* and *King George V* classes and later, the rangefinder was placed beneath a revolving armoured hood (the Argo Tower) atop the conning tower. In earlier classes (except *Hercules*), the Argo mounting was located aloft, where necessary in an enlarged (fore) top.[115]

However, by the time it entered service, the Argo mounting was no longer the only source of ranges. In 1908, Bacon began the search for a suitable means to fit rangefinders in turrets.[116] In 1910, supply had started of 9-foot armoured rangefinders for one turret in all ships from *Dreadnought* to the *Orion* class, and for two turrets in *Lion* and *Princess Royal*. However, consideration was then being given to the local control of fire, which would require a rangefinder for every turret.[117] By mid-1912, such provision had already been approved for the *King George V* class, *Queen Mary* and later ships[118] while, by the next year, it had been extended to the turrets of all dreadnoughts.[119]

Also in 1908, an order was placed with Barr and Stroud for a trial FR rangefinder of 15-foot length.[120] On handing over to his successor, Captain Archibald

[111] *Fire Control Instruments 1914*, pp.25-6 and Plates 65-6, 68-9. *Annual Report of Torpedo School 1912*, pp.64-5, 109M91/ART2, HRO
[112] *DNO for Successor* July 1907, p.26.
[113] *DNO for Successor*, November 1909, p.19.
[114] Delivery was scheduled to begin in September 1911: J C W Henley to Dreyer 13 August, 1910, DRYR 2/1, CC. 15 of the 45 sets ordered had been delivered by February 1912: *IDNS*, pp.196-201 and 214. Sufficient mountings had been purchased for 'one per ship for battleships and battle-cruisers, "Dreadnought" and later': *DNO for Successor*, May 1912, p.15.
[115] Brooks, 'Mast and Funnel Question' (*op. cit.*) pp.44-50. In *Hercules*, the Argo mounting was on the compass platform. See also John Roberts, *Battlecruisers* (London, 1997), pp. 28 and 69, copy courtesy the author gratefully acknowledged.
[116] *Fire Control*, 1908, p.6. *DNO for Successor*, November 1909, pp.5 and 19.
[117] Minutes on 'Local Control of Turret Gunfire', Oct.-Nov. 1910 in 'Local Control of Turret Guns. Special Firing by HMS Vanguard....' in ADM 1/8147.
[118] *DNO for Successor*, May 1912, p.7.
[119] *Home Fleet General Orders*, '39. Local Control', 15 September, 1913, p.2. in DRAX 1/9, CC.
[120] *Range and Vision*, p.79. *SPG, January 1908*, p.17.

Moore, Bacon reported that it 'has given good results. It is being returned to the makers to remedy certain defects before further trials take place'.[121] However, when Moore was promoted to Controller in May 1912, he informed his successor (Captain F C T Tudor) that:

> Some two years ago Barr and Stroud submitted a 15-foot range-finder for trial...but the gain in accuracy was not as great as might be expected.
> A second 15-foot, much improved, has been purchased for the B turret of the "Ajax"....[122]

This improved model was probably of the recent FT design, which the Glasgow firm then used as the basis for their standard 15-foot instrument, the FT24, in production by 1913.[123] Thus it seems that Barr and Stroud had taken several years to eliminate the unspecified defects found in the FR. However, although, from 1913, they were regularly supplying foreign navies with 12- and 15-foot models,[124] the Admiralty showed little urgency in procuring these more accurate instruments. Apart from the single trial instrument (later moved to *Orion*), the 15-foot FT24 was only ordered in quantity for the *Queen Elizabeth* class.[125]

Jellicoe and his two successors all invited Thomas Cooke and Sons to submit rangefinders for trial.[126] A principal motivation is made clear by Bacon.

> The trials of the Cooke 10-foot range-finder showed this to be an excellent instrument, but the price was found to be prohibitive. This is regrettable, as the introduction of this range-finder would have started competition with Barr and Stroud's.[127]

After comparisons between 12-foot instruments from the two firms, Moore concluding that:

> ...the Cooke appears to have better light-gathering capacity, and possibly, owing to this cause, greater accuracy.[128]

There is no reason to doubt that the Cooke-Pollen rangefinder[129] was an excellent if expensive instrument; the Russian Navy preferred it to the Barr and Stroud even though

[121] *DNO for Successor*, November 1909, p.19. For the very favourable trial report, see Admiralty, Gunnery Branch, *Progress in Gunnery Material, 1922 and 1923*, p.40, ADM 186/259.
[122] *DNO for Successor*, May 1912, p.7 and 15.
[123] *Range and Vision*, pp.78-9.
[124] *Naval Annual 1913* (*op. cit.*) pp.315-7.
[125] Admiralty, Technical History Section, *The Technical History and Index*, 'Fire Control in H.M. Ships', TH23, December 1919, pp. 32-33, AL.
[126] H Dennis Taylor to DNO, 4 June 1907, in 'Invention of 15' Range Finder, Sea going tests of', in ADM 1/8051.
[127] *DNO for Successor*, November, 1909, p.19.
[128] *DNO for Successor, May 1912*, p.15. See also *PGM 1922-3* (*op. cit.*) p.41.
[129] Patent 30,090 applied for 31 December 1912.

it cost three times as much.[130] However, the Admiralty's policy of fitting many rangefinders in each ship, and Cooke's close association with Pollen, made it doubly difficult to secure orders. Eventually, in March 1918 when Dreyer was DNO, 30 Cooke rangefinders were ordered but, overburdened with other work, the firm was only able to deliver ten by the time hostilities ended,[131] so Barr and Stroud's monopoly position still remained unassailed.

Even the latest and best rangefinders could only generate accurate ranges if worked by trained and experienced range takers. In early 1910, the Inspector of Target Practice (Rear-Admiral Richard Peirse) insisted on the need for proper training and regular courses of instruction, while the DNO urged the Board, unsuccessfully, to introduce the non-substantive rating of range taker.[132] The conference convened after the unsatisfactory 1911 Battle Practice concluded that: 'The supply of a properly qualified Seaman or Marine Rangetaker for every 9-ft. rangefinder...is urgently required' and again proposed the introduction of the rating of rangetaker.[133] The DNO made the same submission in April 1913[134] and repeated it yet again in December after the *Empress of India* firing had shown that 'the Range-takers...are at present the weak spot in our fire Control personnel'. Even then, another six months was to pass before, at last, the Board gave its approval on 19th July, 1914.[135] Thus, there must be some doubt about the standard of training of the Royal Navy's rangetakers as hostilities began.

DUMARESQS

In February 1908, while serving as an assistant to the DNO, Lieutenant Frederic Dreyer suggested an arrangement of gearing which would enable the main dial and the enemy bar of a Dumaresq to rotate together during an alteration of own course, but, although the mechanical details were worked out by Elliott Brothers[136] after consultation

[130] Correspondence between Pollen and AJ Balfour 29 February - 3 March 1916 in T.173/91 Part VII.
[131] *Technical History*, 1919 (*op. cit.*) p.33.
[132] Minute ITP to DNO, 18 May 1910 in 'Gunnery: Effects... of new developments'. DNO's minute, 18 October 1910, 'Local Control of Turret Guns (*op. cit.*).
[133] 'Report of Conference on Gunnery', para.38 in 'Gunnery in the Royal Navy, Conference at Admiralty, Dec, 1911/Jan 1912, Report and action' in ADM 1/8328.
[134] 'IQ/DNO III, 1914', (*op. cit.*) p.60.
[135] Admiral G. Callaghan to the Secretary of the Admiralty, 8 December 1913, para.12 and DNO's remarks and actions thereon in 'Gunnery practice at Sea. Sinking of HMS Empress of India 4/11/13', ADM 1/8346. 'Increase to G & T Complement of Battleships and B'Cruisers, 23 July 1914 in IQ/DNO III, pp.39-60.
[136] For Elliott's early history, see Gloria Clifton, 'An Introduction to the History of Elliott Brothers up to 1900' and H.R. Bristow, 'Elliott, Instrument Makers of London, Products , Customers and Development in

with Dreyer, no experimental instrument was then constructed.[137] By 1909, the Mark II Dumaresq had been modified by the addition of two circular scales to indicate own and enemy compass courses; these were intended to assist in keeping the rate through a turn by own ship, though all adjustments had to be made by hand. In addition, the new dial plate was graduated for range-rate in yards per minute, while the straight deflection lines were supplemented (for use with a bearing plot) by curved lines of constant bearing rate.[138] This design was the basis for the Mark III, the designation Mark II* being used for Mark II instruments modified to the same standard.[139]

The Mark IV Dumaresq was developed during 1910 for use in turrets under local control. After conferences in June with Commander R Backhouse (Experimental Commander at Whale Island)[140] and with Commander J Henley at the Admiralty, the design 'was worked out into practical form by Elliott Brothers'. While the Mark IV was a simplification of Dreyer's original idea from 1908, the Mark VI Dumaresq, for control tops, was a complete realisation. The initial design was developed at Whale Island by Lieutenant Prickett, a model being shown to Keith Elphinstone of Elliott Brothers, in December 1910; Elliotts then added a 'considerable number of minor points of improvement in design'. The gearing was arranged so that, as the operator followed the target by rotating the dial, the enemy bar and the course scales revolved through the same angular amounts. This was, in fact, an approximation. However, as explained in Appendix VII, the errors were only significant when the speed-across was high: and, even then, were correctable by reference to a compass. The instrument was designed for easy of use rather than theoretical exactitude.

In March 1914, Elphinstone proposed a number of detailed improvements mainly concerned with setting and reading the scales; they were incorporated in the Mark VI*, first ordered in October 1914. Up to 6 January 1913, Elliotts had supplied a total of

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the 19th Century' in *Bulletin of the Scientific Instrument Society*, No. 36, March 1993, pp.2-11, copy courtesy of Mr Ron Bristow.

[137] Elphinstone, 'Dumaresq History' (*op. cit.*). Where not otherwise cited, this is the source for the statements in the remainder of this section. A copy of Elliott's drawing E.S. 1165 of 6 February 1908 is in T.173/91 Part III (with a quote of £19 to 20 for manufacture).

[138] Admiralty, Gunnery Branch, *Information regarding Fire Control, Range Finding and Plotting*, 1909, pp.14-17 in 'Miscellaneous Gunnery Experiments 1901-1913', Ja010, AL.

[139] Admiralty, Gunnery Branch, *Manual of Gunnery (Volume III) for His Majesty's Fleet 1915*, p.171, AL.

[140] Travers, *House That Jack Built* (*op. cit.*) p.166.

1,042 Dumaresqs at the modest cost of £9,539; simple models like the Mark IV turret instrument cost only £4/10/0.[141]

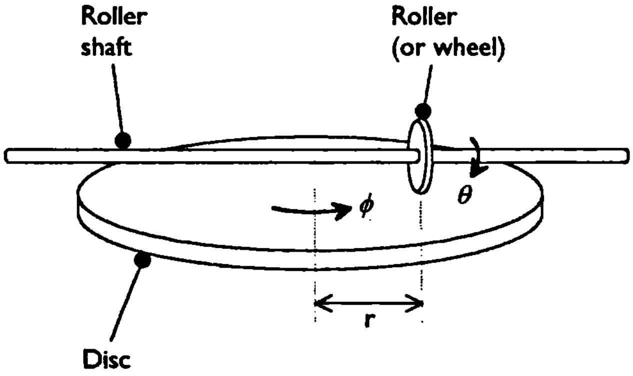
THE VICKERS CLOCK

By mid-1907, two or more Vickers clocks (Plate 3) had been supplied to ships with electrical fire control.[142] A complete rotation of the range pointer registered a change in range of 4,100 yards but 'the graduations are numbered through windows in the face so that 3 ranges are available, 2,000-6,000 6,000-10,000 and 10,000 to 14,000 yards'.[143] The first production models were calibrated for rate both in knots (maximum 38.6) and in seconds to change 50 yards (minimum 2.3 seconds);[144] these limits correspond to a maximum rate of 1304 yds/min. By 1909, rangekeeping by stop-watch was evidently considered unnecessary, since the rate graduations of Dumaresqs, clocks and rate instruments were all changed to the more convenient yards-per-minute.[145] Thus the Barr and Stroud Mark II rate instruments fitted from the *St. Vincent* class onwards showed the rate in steps of 10 up to a maximum of 1990 yds/min. increasing or decreasing.[146]

In Defence of Naval Supremacy states categorically that the 'motor [of the Vickers clock] could not be made to vary in speed continuously....the speed...was altered in steps'.[147] In fact, the clock was based on a conventional disc-and-roller variable-speed drive (Fig. 3.1) with springs driving the 'rotating disc at a constant speed controlled by a governor'.[148] The variable speed was obtained by moving the roller along the diameter of the disc: and it is clear from the clock's mechanism (Plate 9) that the roller could be moved continuously by means of the threaded rods coupled to the rate handle. In 'The Quest for Reach', Professor Sumida attributes his earlier interpretation to some misleading statements by Arthur Pollen. However, the same article states:

> Changes in the indication of the rate by the dumaresq had to be transferred manually to the Vickers clock, and because the transfers could not be carried out continuously, continuous change in the range rate was imperfectly represented by the clock to a

[141] 'Local Control of Turret Guns', 1910 (*op. cit.*). Elphinstone, 'Dumaresq History'. *Manual of Gunnery 1915* (*op. cit.*) pp. 172-5; the Marks V and VII were for use in control towers. Claim 1999 Form 3 by Major R G F Dumaresq to Royal Commission on Awards to Inventors in T.173/91 Part XI.
[142] *SPG, January 1907*, p.18. *DNO for Successor*, July 1907, p.20.
[143] Admiralty, Gunnery Branch, *Addenda (1909) to Gunnery Manual Vols. I (Part I) and III*, November 1909, p.54 and Plate XXVII, Ja254, AL.
[144] *SPG, July 1906*, p.24.
[145] *Fire Control and Plotting*, 1909 (*op. cit.*) pp.17 and 31.
[146] *Fire Control Instruments 1909*, pp.10 and 28.
[147] *IDNS* (*op. cit.*) p.75 and also pp.217-8.
[148] *Addenda (1909) to Gunnery Manual* (*op. cit.*) p.54.



The rate of rotation of the roller shaft is proportional to the rate of rotation of the disc and distance r of the roller from the disc's centre.

$$\dot{\theta} \propto r\,\dot{\phi}$$

If the disc rotates at constant speed and if the roller's distance from the centre is proportional to the range-rate:

$$\dot{\theta} \propto \dot{R}$$

Thus the rotation-rate of the roller shaft is proportional to range-rate: and the rotation of the shaft is proportional to the change of range.

$$\theta_2 - \theta_1 \propto R_2 - R_1$$

where the suffices indicate values at times t_2 and t_1.
The variable speed drive integrates range-rate to give change of range.

FIG. 3.1: VARIABLE SPEED DRIVE

greater or lesser extent depending on the rapidity of change and the time intervals between resettings.[149]

It also establishes that, when necessary, the rate was altered as frequently as every quarter-minute; this gave time to read the latest rate from the Dumaresq, set it on the rate transmitter, read it off the rate receiver and adjust the clock rate accordingly. Nonetheless, the clock-rate and, therefore, the clock-range lagged behind the true rate and range: but by how much? While in some cases the rates may have been transmitted at fixed intervals, it must have been much easier to transmit the rates in fixed steps; when the rate was changing especially rapidly, the only practicable method was to alter the rate each time the Dumaresq pointer crossed a major rate division on the dial i.e. in steps of 100

[149] 'Quest for Reach', pp.12 and 39. 'For a revealing indicator of the dangers of manual transfers...', Sumida cites but does not quote *Fire Control*, 1908 pp.48-9; the relevant passage only advises: 'Clock operators should be carefully trained. There should be no chance of their setting the rate in the wrong direction. A convenient way...is to paint a red patch next each of the "increasing" divisions on the rate scale and also...next the [engraved] words "range increasing". Similarly black patches on the "decreasing" side'.

yds/min.[150] Appendix VIII gives a detailed analysis of two 25-knot ships on opposite courses passing beam-to-beam at 8,000 yards. It shows that, whenever the rate was changed frequently in equal steps, the lagging error of the clock-range behind the true-range can be expressed very simply. To a good approximation, it increased at a rate of half the amount of each rate-step. Thus, if the rate-step was 100 yds/min., the lag increased by 50 yards in each minute. However, the rate changed by as much as 100 yds/min. in a quarter-minute only when the range was close to the minimum value on a sharply-curved range-time hyperbola; in most cases, steps of 50 yds/min. would have been practicable, halving the lagging error rate to 25 yds/min.

In use, the Dumaresq could only keep the rate if the target bearing arrow was kept pointing at the target: that is, if the target remained visible. But in that case, before opening fire the clock could be tuned to the rangefinders: and, once firing began, it was continually corrected (in steps of not less than 100 yards) by spotting. Thus, if a significant lagging error did accumulate after several minutes, it could always be corrected by observation.

'The Quest for Reach' also notes that 'the disc-roller drive of the early production Vickers clocks is known to have been mechanically unsatisfactory' and refers to 'the weakness of the drive, which meant that it could not be connected to a transmitter'.[151] However, since the clock had been designed as a self-contained instrument powered by springs, it had never been intended to drive step-by-step transmitters directly. Appendix IX describes what is known of its development history, which shows that problems arose not in the disc-and-roller mechanism, but in keeping the disc rotating at a constant speed, irrespective of the rate setting. By 1909, satisfactory speed regulation had been achieved by assisting the governor with a 'compensating brake'.[152] The appendix also analyses the slippage between disc and roller while the rate was changing: and discusses the probable causes of the 'check' or 'little stoppage', as observed during the post-War RCAI hearings when the rate was altered.[153] It concludes that the separate errors due to these effects were usually negligible: that they were always less than those due to the stepwise setting of the rate: and that, in some circumstances, they could tend to cancel out. The Vickers clock was by no means a perfect mechanism: but its accuracy was

[150] *Technical Comparison*, Chapter V, Fig.6 shows the dial graduations.
[151] 'Quest for Reach', pp.87 and 60.
[152] *Fire Control* 1908, p.5. *SPG, July 1908*, pp.8-9. *Addenda (1909) to Gunnery Manual*, p.54.
[153] Examination of Mr R H Ballantyne in T.173/547 Part 12, pp. 54-5 and 92-3.

sufficient for its purpose: which was to keep the *change of range* in the intervals between corrections to the clock range derived either from the mean rangefinder range or from spotting.

OTHER FIRE CONTROL INSTRUMENTS

Several calculators, some quite elaborate like Captain John Dreyer's Direct Reading Range Corrector, were devised to remove the need to consult ballistic tables or make calculations during firing.[154] In 1909, Macnamara time-of-flight watches were mentioned in a report on concentration experiments, though they were not available to the ships taking part.[155] By 1913, they were considered 'indispensable' for concentration firing[156] and were recommended for use in main and local control positions.[157]

Finally, three more instruments show how the firm of Elliott Brothers successfully expanded their business as a supplier of fire control devices to the Admiralty by manufacturing designs which, probably in all three cases and certainly in the last two, originated elsewhere. In 1909, they were making the Robinson anemometer (which gave a direct reading of apparent wind speed and direction and of the wind-you-feel along and across the line of fire)[158] and the first examples of the Forbes speed log. By 1912, speed logs were standard in all dreadnoughts for keeping the Dumaresqs correctly set for own speed.[159]

In 1910, Elliott Brothers signed an agreement to manufacture and sell the Anschütz gyro compass in Britain and the colonies. Technology transfer was not only one way, Elliott's granting Anschütz a licence for the Forbes log in 1911.[160] However, as explained in Chapter 2, the Anschütz gyrocompass was not sufficiently accurate for all

[154] *Addenda (1909) to Gunnery Manual*, p.19 and *DNO for Successor*, November 1909, p.18. For Dreyer's Calculator, see *DNO for Successor*, July 1907, p.22 and *Fire Control* 1908, p.44 and Enclosure XIVa.

[155] Admiralty, Gunnery Branch, *Fleet Fire Control and Concentration of Fire Experiments*, 1910, p.7 in Ja010 AL, copy courtesy Mr John Roberts.

[156] Captain, *King George V* to VAC Second Battle Squadron, 7 November 1913 in ' Empress of India', 1913 (*op. cit.*).

[157] *Home Fleet General Orders*, '14. Fire Control Organisation', 5 November 1913, p.4 in DRAX 1/9. See also Dreyer, *Sea Heritage*, p.75 and *Manual of Gunnery 1915*, p.21.

[158] *Addenda (1909) to Gunnery Manual*, p.19.

[159] *DNO for Successor*, November 1909, p.16 and May 1912, p.13. For a full description, see Elliott Brothers (London) Ltd., *Forbes' Ships' Log and Speed Indicator*, London, n.d. in the Elliott Archive (2.61) Its inventor, Professor Forbes, had previously but unsuccessfully submitted a design for gun sights: *DNO for Successor*, February 1905, p.17 and July 1907, p.24.

[160] Fred T. Jane (ed.), *Fighting Ships 1911* (London) pp. 519-21. This article uses part of the text of G K B Elphinstone, *The Anschütz Gyro-Compass* (London: Elliott Brothers, 1910) Elliott Archive (2.23). The archive also contains copies of the 1910 and 1911 agreements between Anschütz and Elliotts.

gunnery purposes and, in comparative trials with a Sperry compass conducted in 1913, showed both a larger error and rate of change of error.[161] Once the War had severed Elliott's connection with their licensor, Sperry replaced them as the established supplier and even Anschütz compasses already in service were replaced.[162]

MANUAL FIRE CONTROL AND PLOTTING

Until they were eventually fitted with the Dreyer Tables Mark I (Chapter 5), the fire control systems in British 12-inch dreadnoughts relied at several points on the unaided manual transfer of data between instruments: specifically from Dumaresq (latterly the Mark VI) to clock, from clock to the cross-connecting gear, and, in the earlier ships, to the gun sights. This manual system also used manual plotting, but it required a three-year 'experimental plotting period'[163] from 1908 to 1911 before manual course plotting was discarded in favour of manual rate plotting.

A towed target was introduced for the 1908 Battle Practice. In May 1908, after the rejection of Pollen's automatic plotter, the first recommendations were issued to the Fleet on the use of manual plotting to determine target course and speed. The pamphlet *Fire Control* contained Wilson's description of the virtual course system tried in *Vengeance*. Bearings were taken simultaneously with ranges by means of a Chetwynd liquid compass mounted on the rangefinder mounting. This type of compass was 'constructed so that the card might be affected as little as possible by the motion of the bowl'; it was, therefore, not unpromising as a cheaper alternative to Pollen's gear: even though, in the *Vengeance* experiments, the bearing errors had been too great to make a useful virtual-course plot when the bearing-rate was low.[164] Dreyer contributed to the pamphlet a separate section which included a description of time-and-range (and time-and-rate) plots and the setting of the Dumaresq by a cross-cut of rates; however, bearing-rate was to be obtained from

[161] *Annual Reports of the Torpedo School, 1912*, p.69 and *1913*, p.121 in 109M91/ART2, HRO. 'Very severe rolling and pitching was imparted to the compass[es]...both...indicated a rapid "yaw effect" of over a degree'. However, longer-term meaned fluctuations were 1°/5.7° for error while the time for the error to change by 1° was 20/4 minutes in favour of the Sperry.
[162] *Technical History*, 1919, p.20. In 1916, the Anschütz gyros were reused in the first 17 sets of Henderson gyro firing gear for Director sights. For the history of the Anschütz compass in the Royal Navy, see A E Fanning, *Steady as She Goes* (London, 1986) pp. 175-180, 195-199.
[163] Captain Tower's evidence to the RCAI, T.173/547, Part 11, p.8.
[164] 'Report of Admiral of the Fleet Sir A.K.Wilson' in *Fire Control* 1908, pp.26-7. *Chetwynd's Patent Liquid Compass*, pamphlet, n.d. and compasses ACO 163, 164, 168 and 168A, NMM, examined courtesy of Dr. Gloria Clifton. The card diameter in this type of compass is about three-quarters that of the bowl.

timed bearings, not a plot.[165] Wilson advocated his own scheme only as 'a guide for officers carrying out further experiments' and for further trial in 'not less than six ships with different descriptions of armament'. Similarly, Dreyer's 'Hints' began: 'It is not advisable to lay down any exact rules [which] would probably tend to fetter initiative and delay improvement'.[166] The DNO, Reginald Bacon, while agreeing that six ships should be completely fitted for virtual course plotting, hoped that 'in a very short time the time curve method will be in general use and good practical results in firing at moving objects should be obtained'. By May 1908, the Board had approved the purchase of training gear for rangefinders and of 142 roller boards, T-squares and squared paper for time-and-range plotting.[167] However, neither they nor any other special Service plotting gear were ready for that year's practice,[168] although fifteen to twenty gunnery lieutenants obtained manual straight-course plotters from Pollen, which were also copied by others.[169] Thus, for 1908: 'makeshift arrangements were necessarily practised this year i.e. Plotting Boards were often employed aloft etc., and the bearing arm kept actually trained on the target'.[170] The outcome was summarised as follows.[171]

Plotting method	Numbers of ships		
	using	giving insufficient information	obtaining satisfactory results
Enemy Course	33	4	18
Virtual Course	8	3	4
Range and Time	13	5	4

Indomitable and *Dreadnought*, which were ranked first and fourth in the Home Fleet, may have used virtual course, since they were among the six ships nominated by the DNO to be fitted according to Wilson's recommendations.[172] Yet an essay on fire control for the War College declared that: 'no instance has come to light of any Ship making successful

[165] 'Hints on Battle Firing' in *Fire Control*, 1908 pp.50-4. For Dreyer's authorship, see *Technical Comparison*, p.10.
[166] *Fire Control* 1908, pp.26, 35 and 47.
[167] DNO's minutes of 18 March and 27 May 1908 in 'Experiments in "Vengeance". Report of Admiral Wilson'. See also *IDNS*, p.136; however, 'Quest for Reach' (p.65) implies that Wilson's system was more generally adopted.
[168] *Fire Control and Plotting*, 1909, p.31.
[169] *IDNS*, p.149.
[170] 'Fire Control', An Essay by Captain C Hughes-Onslow, n.d. but 1909, Section II, p.21, PLLN 1/5, CC.
[171] *Fire Control and Plotting*, 1909, p.30.
[172] Admiralty, Gunnery Branch, *Results of Battle Practice in His Majesty's Fleet 1908* in Ja 156, AL. DNO's minute 27 May 1908 (*op. cit.*).

use of the Virtual Plot combined with Time and Range diagram' and that 'experience...in 1908 shows this system to be difficult and un-natural'.[173] As Dreyer later recalled, in 1908 rate-plotting was also 'badly received afloat, as "straight-line" plotting, with the power to forecast the range for some minutes ahead was...considered far superior by the majority'.[174]

A new pamphlet issued before the 1909 Battle Practice confirmed that the Fleet would soon be issued with new equipment, including the time-and-range boards: Chetwynd compasses and the fittings to modify the rangefinder mountings: and the gear to adapt rate instruments to the transmission of ranges from aloft. However, it said little about time-and-range plotting but concentrated on course plotting with a new Admiralty-pattern plotting instrument. This used a cone-and-wheel continuously variable speed drive to rotate the lead screw advancing the pencil plotting own ship's course; since the screw was positioned along one edge of the paper, the pencil could move in both directions.[175] Pollen also supplied thirteen more 'slightly improved' manual plotters;[176] assuming that these resembled his patents of 1908-9, the lead screw ran down the centre of the plot: but its speed could only be changed in steps, by means of interchangeable discs of different diameters. Both these instruments were essentially straight-course plotters. However, the Admiralty pamphlet and the Argo patent each proposed similar methods to plot while own ship was turning; these depended on knowing the diameter of ships' turning circles at different speeds and angles of helm, and on pivoting the paper on the plotting boards about appropriate centres of rotation. Particularly with the benefit of hindsight, both proposals seem equally impractical.[177]

Lectures by the staff of the Inspector of Target Practice on the 1909 practices, prepared at the end of the year, stated that all but one of the ships inspected 'plotted the true course and speed of the enemy': though these must actually have been straight-course plots. Thus virtual course seems already to have been abandoned. Of 39 ships, 11 obtained the course to within half a point and 16 to within one point, although the

[173] Hughes-Onslow, 'General Remarks...on Plotting', p.1 and Section III, p.1.
[174] 'A Short History of Range Plotting in the Royal Navy' appended to 'Some comparisons made between the Argo Clock and the Fire Control table in "Monarch" ', n.d. but 1912 in T. 173/91 Part VII. The style, with its frequent underlinings, is unmistakably Dreyer's.
[175] *Fire Control and Plotting*, 1909, pp.10-12, 31. *Technical Comparison*, p.7.
[176] *IDNS*, p.150.
[177] Patent 5031 of 1909 (applied for 2 March 1909) references 25,654 of 27 November 1908, which describes the drive with interchangeable discs: see further Appendix XII, Note 5. *Fire Control and Plotting*, 1909, p.9.

average time to complete the plot was 5.2 minutes. Taking simultaneous ranges and bearings proved especially difficult in a seaway, while results were also noticeably inaccurate if plotting was continued after opening fire. The ITP's staff concluded that:

> Plotting is not yet sufficiently developed to be of practical use under general service conditions....
> The future of plotting depends upon the development of the rangefinder mounting, a more accurate method of obtaining bearings and measuring the observing ship's speed...[178]

They also described the difficulties with continuous aim experienced by *Inflexible* and some pre-dreadnoughts: with range transmission and sight-setting when the rate was high: and with target indication.

Sumida cites these lectures as evidence that 'the entire Inspectorate had been transformed into a bastion of opposition to the policy of the Ordnance Department'.[179] Yet the second lecture begins:

> The opinions expressed must not be taken as fundamental, but contingent to the progress in materiel.

The ITP's staff also found that 'a large number of ships' achieved 'considerable success' more quickly with the help of the range-rate plotting preferred by Bacon.

> The Dumaresq is first adjusted to the estimated course and speed of the target, the range-finder observations are plotted with the times on squared paper, and the clock is started with the meaned range and rough rate. The amount the clock gains or losses [*sic*] on the meaned range is the error in rate; the clock and Dumaresq are then corrected accordingly.[180]

Further, by the time the lectures were delivered, all the Inspectorate's concerns were being addressed. The production order for Argo mountings was being negotiated (Chapter 4); laying and training gear was being improved in both new and old ships; *Neptune*, laid down in January 1909, was the last dreadnought without Vickers follow-the-pointer sights; Forbes logs were already under trial and the first Evershed installation imminent. To represent the departments of the DNO and ITP as fundamentally opposed[181] is an exaggeration which obscures their true relationship. The position of ITP had been created to ensure 'that improvements are quickly carried out

[178] ITP, 'Battle Practice 1909' (*op. cit.*) ff. 2-3, 7-8 and 17-18.
[179] *IDNS*, pp.154-5.
[180] ITP, 'Battle Practice 1909', ff. 9 and 11.
[181] K G B Dewar was one of the ITP's staff but, while criticising the 'most favourable conditions' of Battle Practice (pp. 112-4), he does not mention any rift between ITP and DNO: *The Navy from Within* (London, 1939).

and new ideas promptly taken up'.[182] Thus he and his staff were expected to criticise systems and equipment provided by the Admiralty, and to report on experimental techniques like manual course plotting. These lectures are, therefore, evidence only of the expected tensions within the naval hierarchy between supply departments and a department established to assess the shooting of the Fleet and to improve its material and technique.

During the tactical exercises conducted by Admiral Sir William May in early 1910 with the Home Fleet, it was found that, with practice, enemy course could be estimated to within a point by eye, which error was equivalent to only about 100 yds/min. This was as accurate as all but the best course plotting, yet incurred no delay. Admiral May concluded that, in poor visibility, fire could not be withheld to give time to plot: while, in good visibility, tactical manoeuvring largely negated the results from plotting before they could be used. He also confirmed that the system described by the ITP's staff, in which the clock range and rate were 'tuned' to follow the mean rangefinder ranges, was 'used very generally now' and the 'rate...has almost invariably been arrived at some time before any "plotting" results'.[183] All manual course plotting (including virtual course) was also rejected by the Colville Committee in July 1910, even though the alternative under consideration (Pollen's first attempt at a true-course plotter then under trial in *Natal*) had failed to work.[184] After the conclusion of the *Natal* trials:

> ...the Admiralty ordered a further comparative trial between "Africa" using virtual plotting and "Superb" using Time and Range plotting assisted by clock tuning. From this trial, "Superb" emerged victorious....[185]

The conclusions from these trials came too late to influence the 1910 Battle Practice. Of 61 ships witnessed by the ITP, 43 still used course-and-speed plotting,[186] while 10 preferred time-and-range. The important change was that 8 ships employed dual-rate plotting.[187] Even Dreyer acknowledged that the first dual rate plots of ranges and bearings were made by Lieutenant (N) A H Norman of *Arrogant* in 1908 and later used in her

[182] Padfield, *Aim Straight* (*op. cit.*) p.146.
[183] Captain Richmond (*Dreadnought*) to C.-in-C. Home Fleet, recvd. 24 March 1910 and Admiral May to the Secretary of the Admiralty (H.F. No. 803/0194) 25 April 1910 in 'Gunnery: Effects...of new developments'.
[184] Enclosure I, p.2 with Colville Committee to C. in-C. Home Fleet, 1 July 1910 in DRAX 3/3.
[185] *Technical Comparison*, p.8.
[186] Despite widespread dissatisfaction; see Jon Sumida (ed.) *The Pollen Papers* (London, 1984) pp.260-2 for letters to Pollen from gunnery officers.
[187] 'Summary', p.11 in DRYR 2/1.

delayed 1908 battle practise on 24 February 1909: and also in her 1909 practice.[188] Norman presumably plotted bearings from a Chetwynd compass: but, by August 1910, it was expected that:

> The plotting of ranges and bearings will be greatly facilitated when Pollen's rangefinder is supplied as the two [plotting] operators will have the ranges and bearings automatically transmitted to receivers in front of them.[189]

With accurate bearings in prospect, by early 1911 opinion had swung decisively in favour of rate plotting.

> The system now recommended is Time and Range and continually tuning up the Range Clock with the Range Finder, in addition the Rate on the Range Clock being manipulated as necessary in order to make the Range Clock run in agreement with the Range Finder thus obtaining the rate...
> When a reliable bearing instrument has been obtained, the system...which most commends itself is... to plot -
> Time and Range and Time and Bearing on two diagrams and from these data setting the Dumaresq to the Course and Speed of enemy.
> The most convenient method of plotting the Time and Range diagram is to utilise the Admiralty Plotting instrument...
> The Admiralty Time and Range Board is also suitable for Time and Range or Time and Bearing Plotting.[190]

Another factor encouraging the adoption of a fire control system based on rate was a wider use of rate spotting. This was not new[191] but the *Manual of Gunnery* for 1911 provided the first official guidance on the method.[192] However, it was another two years before the rate spotting rules were simplified so that the rate was altered in fixed steps: of 100 yds/min. for targets abeam.[193]

INNOVATION AND PROCUREMENT

The completed British manual fire control system incorporated many new instruments, most of which had not even been conceived when the first attempts at long

[188] *Technical Comparison*, p.10. Dreyer and Tower to RCAI, T.173/547 Part 11 p.8, Part 17 p.43 and Part 18 p.20. ITP, 'Battle Practice 1909' f.12 mentions Norman but not dual-rate plotting; it also describes a dual-rate scheme due to Lieutenant Burke of *Suffolk*, in which two clocks were tuned to the ranges and bearings without the aid of plots.
[189] Admiral May to the Secretary of the Admiralty, 1 August 1910 in 'Invention by Commander Dreyer - improved method of obtaining the range...' in ADM 1/8147.
[190] The Secretary of the Admiralty to Commanders-in-Chief and Officer Commanding, 15 February 1911: copy of DRYR 2/1, CC and reproduced in *Technical Comparison*, p.9.
[191] 'Previous to the introduction of Rate Plotting early in 1908...in a few ships spotting corrections for Rate were also made': 'Remarks by Commander F.C.Dreyer R.N. on the question of how to best obtain and maintain the gun range in action', 22 July 1910 in T.173/91 Part III.
[192] *Manual of Gunnery for His Majesty's Fleet 1911*, pp.11-12, Ja254, AL. See also 'Long Course Lecture Notes, 1910-11', 4 March 1911 in Papers of Commander D T Graham Brown, *Excellent* Historical Library.
[193] *Home Fleet*, 'Fire Control, 1913 (*op. cit.*) p.4.

range firing were made at the turn of the century. The progress in material had been accomplished with largely unchanged resources. In 1912, just one of the DNO's assistants, Lieutenent C V Usborne, remained responsible for:

1. Fire control and communications.
2. Range-finders and plotting.
3. Sights.
4. Calibration.
5. Ballistic questions and range tables.
6. Alterations and additions, including estimates.
7. Attends gun trials.

as well as for handbooks on fire-control and other matters. He did at least now share the assistance of one warrant officer, while one of the torpedo assistants dealt with 'experimental and new designs of electrical fittings [including] fire control'.[194] By 1914, the DNO's gunnery assistants remained at five, one attending to fire control, another to the Director. In a post-War report, the DNO was described as 'heavily and consistently overworked', which must also have applied to his assistants;[195] with considerable understatement, Reginald Bacon recalled that:

> The whole of the DNO's staff was none too large to deal with the work in hand'.[196]

With such limited manpower, the procurement of the new components could not have been accomplished had not much of the design and development been done by the Admiralty's industrial suppliers, both established and new. Though with some delays, Barr and Stroud introduced more accurate rangefinders as they were needed. While the firm enjoyed an effective monopoly in rangefinders, both Siemens and Vickers provided effective competition in fire control instruments, Vickers eventually establishing themselves as the sole source of follow-the-pointer and director gear. Eversheds brought new technology to the problem of target indication.

The vital advances in sighting and aiming were achieved by several means. A scientific consultant developed the first purpose-designed sight telescopes, but better sights and turret training engines were largely due to the mounting manufacturers. In contrast, the improvements to the hydraulic elevating and training controls were mainly achieved by *Excellent* and Portmouth Dockyard. Unfortunately, other attempts at development

[194] *DNO for Successor*, May 1912, pp. 28-29.
[195] DNO's minute 28 November 1918 and 'Naval Ordnance Department: Proposed Post-War Complement' p.4 in 'Naval Ordnace Department 1918-1920', ADM 116/1849. Jon Sumida, 'British Naval Administration and Policy in the Age of Fisher', *Journal of Military History*, Vol. 54 (January 1990) pp. 20 and 22.
[196] Reginald Bacon, *From 1900 Onwards* (London, 1940) p.162.

within the Navy, like the Vyvyan-Newitt automatic sight and the early elevation-only directors, were not successful.[197] The record was much better when the inventions of naval officers (including even the DNO's assistants)[198] were developed by industry. Percy Scott's special relationship with Vickers may have been anomalous,[199] but it was certainly productive. Elliott Brothers under Keith Elphinstone were particularly successful as a manufacturer of instruments invented by others. In some cases, they added to their product range by licensing designs from inventors like Professor Forbes or, in the case of the gyro compass, from an overseas firm. They were also willing to redesign the inventions of naval officers, even though they were not always successful.[200] Above all, the firm participated from its inception in the evolution of the Dumaresq, not only developing the ideas of naval officers (like Dreyer, Prickett and others) but also incorporating its own improvements into the fully developed production versions.

The commercial and contractual conventions between the Admiralty and industry were also well understood by both sides.

> Usually inventions of importance...are brought to the Admiralty in a more or less complete state...ready for trial....
> If the inventor, or the firm which has taken up the invention, are bearing all the preliminary cost and risk...they are naturally entitled to substantial profits....
> Nevertheless, it is not uncommonly found that...firms...are content with...quite reasonable rates of profit....merely stipulating that they shall have the orders for any gear required by the Admiralty.[201]

Thus, the evolution of the manual fire control system reveals the normal sources of technical innovation and the usual processes and commercial relationships by which ideas were turned into instruments for supply to the Royal Navy at acceptable levels of profit. These norms will be used in the following chapters for comparing and contrasting the very different ways in which the Pollen and Dreyer systems were developed. However, what had actually been achieved with the manual system which preceded them?

[197] For the latter, see Brooks, 'Scott and the Director', pp.155-160.
[198] For Usborne's pointer accelerator for gun-sights, see *Fire Control Instruments 1914*, p.21
[199] As was long recognised: Captain H D Barry to Lord Walter Kerr, 13 May 1904, MS. Selborne 41, f.146. C V Usborne, *Blast and Counterblast* (London, 1935) p.15.
[200] For a 1910 attempt at a true-course plotter, see 'Fire Control Instrument devised by Asst. Paymaster Noyes RN, Reports, &c.' in ADM 1/8145.
[201] Admiralty, *Pollen Aim Correction System. General Grounds of Admiralty Policy and Historical Record of Business Negotiations*, February 1913, p.2, P.1024, AL.

PRACTICES AND RANGES

It might be expected that the results of the annual Battle Practice, held in the second half of each year,[202] would provide some numerical indicators of progress in gunnery. The limited available data are reviewed in Appendix X. In 1908, when the towed target was introduced, *Indomitable*, despite a large turn of 18 points half way through her practice run, made 58% hits at over 8,300 yards.[203] Yet, in 1912, at much the same range and with only a two-point turn at the start of the firing run, the average result was only 17.7% hits and the best about 25%: though, unlike the earlier results, these figures exclude ricochets.[204] Unfortunately, there are no obvious explanations for this apparent decline. However, it is clear that the Battle Practice was intended not only as a test of gunnery but to 'resemble actual conditions of battle as far as can be done under peace circumstances'.[205] Thus, probably even in 1908, it included simulations of damage and casualties in order to test alternative systems and personnel: and it was made 'more difficult year by year'.[206] It was also conducted as a competition for the whole Fleet, large cruisers as well as capital ships, and for the crews of the secondary (6-inch) armament as well as the turret guns. This imposed restrictions on maximum range and appears to have influenced the conditions in other ways; in 1911, when pre-dreadnought battleships still outnumbered the all-big-gun ships by 22 to 14, only 4 of the latter appeared in the top 20 ships.[207] Yet, when these disappointing results were reviewed, no blame was attached to fire control equipment.[208]

Sumida charges that, because the Dreyer Table was 'able to produce acceptable results under the unrealistic and easy conditions of Battle Practice...this was to be a major factor in the rejection of the far superior Argo system'.[209] However, the limited evidence suggests that, after 1909, more emphasis was given in Battle Practice to general preparedness for action, while the 'Commander-in Chief's Special Firings', introduced in 1910, were employed to exercise the fire control to its limits.

[202] *Manual of Gunnery 1911* (*op. cit.*) p.121.
[203] Rear Admiral Inglefield to Admiral Fisher, 18 January 1909 quoted in *IDNS*, p.160.
[204] Admiralty, Naval Staff, Gunnery Division, *Progress in Naval Gunnery, 1926*, Plate 1, ADM 186/271. 'HMS ORION, Battle Practice Run' and 'Class I Ships', both 1912, Craig Waller Papers.
[205] *DNO for Successor*, July 1907, p.30.
[206] VAC Atlantic Fleet to the Secretary of the Admiralty 18 December 1911 in 'Gunnery Conference 1911-12' (*op. cit.*).
[207] Admiralty, Gunnery Branch, *Results of Battle Practice in His Majesty's Fleet 1907 to 1913* in Ja156, AL.
[208] 'Conference on Gunnery', report n.d. but early 1912 in 'Gunnery Conference 1911/1912' (*op. cit.*).
[209] *IDNS*, p.220.

Conditions and scheme of practice to be as ordered by the Commander-in-Chief.[210]

During the appointment of Admiral Sir George Callaghan as C.-in-C. Home Fleets (from December 1911), opportunities were taken to conduct firings at unprecedented ranges. In November 1912:

> ...the "COLOSSUS" carried out practice at a towed target (150ft. by 30ft.) at ranges between 14,000 and 15,000 yards spotting from her own top...seven rounds out of 40 [17½ %] being direct hits on the target.[211]

It had been intended that *Neptune* and *Hercules* should carry out long-range runs at up to 15,000 yards during the firings against the *Empress of India* in November 1913. However, squadron firings were held first and the old ship was so damaged that she sank. Callaghan could only report that:

> It was most unfortunate that it was not possible to carry out the long-range runs...as although everyone is agreed as to the great desirability of hitting first we have little to guide us as to the range at which we can open fire with good prospect of hitting.[212]

In the Spring of 1914, the C.-in-C. authorised (reluctantly, according to Chatfield) the Battle Cruiser Squadron to:

> ...fire at two large towed targets at ranges of 16,000 yards and steaming at not less than twenty-three knots. All five ships fired simultaneously at the two targets, the firing was not too good, nor altogether bad. Our rangefinders could only just measure such ranges and were very inaccurate at them.[213]

These special firings are, therefore, the best available indications of the capabilities of the pre-War manual fire control system at long ranges.

In 1914, the Admiralty issued specific orders that, during the renamed 'Special Gunnery Test':

> Certain ships of each class should open fire at the extreme range of their guns.[214]

As the quotations in Appendix XI show, this new emphasis echoed the frequently-expressed expectations of Callaghan and other fleet commanders that, in good

[210] 'Revised Instructions for the Expenditure of Heavy Gun Ammunition', February 1910 in 'Revised Instructions for the Expenditure of Heavy and Light Gun Ammunition' in ADM 1/8065. In 1913, the rounds allowed per gun were 4 for Battle Practice and 3½ for both the C.-in-C.'s and squadron firings: Enclosure III with Secretary of the Admiralty to Commanders, 6 March 1913 in IQ/DNO.II, 1913, p.63.
[211] DNO's Minute 13 February 1913 in IQ/DNO I, 1912, p. 337-8, AL. See also *IDNS*, p.250.
[212] Admiral Callaghan, memorandum 'Firings to be carried out at "Empress of India" ', and letter to the Secretary of the Admiralty 8 December 1913 in ' Empress of India', 1913.
[213] Chatfield, *Navy and Defence* (*op. cit.*) p.113. Sumida, *IDNS*, pp.251-2 and 284-5, citing descriptions of high speed exercises in DRAX 4/1 (CC) states that these firings 'actually took place in 1913 and not in 1914' at ranges of 12,000 yards. In fact, the 1913 exercises were of rate and range keeping between ships of the BCS, without firing.
[214] 'Instructions for Annual Gunnery Practice', 1914 and draft of 5 April 1914, referencing Board decision of 1913, in IQ/DNO, Vol.III, 1914, pp.1-5 and 324.

visibility, fire would be opened at ranges up to 16,000 yards; however, 'effective range' was generally considered to be about 8,000 to 10,000 yards, the range of Battle Practice. Opinion in the Admiralty was similar; Captain F C T Tudor (DNO since June 1912) held that, since modern ships could knock themselves out at 9,000 yards, they would open fire at much greater ranges.[215] However, the new orders came too late and the Royal Navy entered the War with little experience of firing at extreme ranges.

Professor Sumida attributes the abandonment of 'The Quest for Reach' chiefly to the Admiralty's belief, not shared by the commanders of the Fleet, 'that a battle against the German fleet could be won by rapid fire at relatively close range'. This conviction, he proposes, derived from intelligence reports of the secondary armament of the new German dreadnoughts.

> The adoption of medium-calibre quick-firers...suggested that the Germans would seek to engage at shorter ranges than were being contemplated by the Royal Navy....A knowledgeable British naval officer later recalled that "so firm was the conviction" that the Germans would fight at close range that "our whole tactics were based upon it".[216]

This quotation is taken from a lecture delivered by Captain H G Thursfield in 1922: but it is incomplete, the passage concluding:

> ...therefore we must endeavour to avoid it [a close range action]: we must develop and practice the game of long bowls.[217]

This does seem a more rational response; why press in with less well armoured ships to ranges at which the German 5.9-inch guns (and, indeed, the latest torpedoes) were more likely to be effective?[218] However, since Bacon had been DNO and May commanded the Home Fleet, there had been agreement that poor visibility in the North Sea could force encounters at short range, when fire would have to be opened immediately. 'The Quest for Reach' does not provide any other strong primary evidence of an intention, held only by the Admiralty, to engage at short ranges even if the visibility was good.[219] Both commanders at sea and the Admiralty recognised that a fire control system had to meet

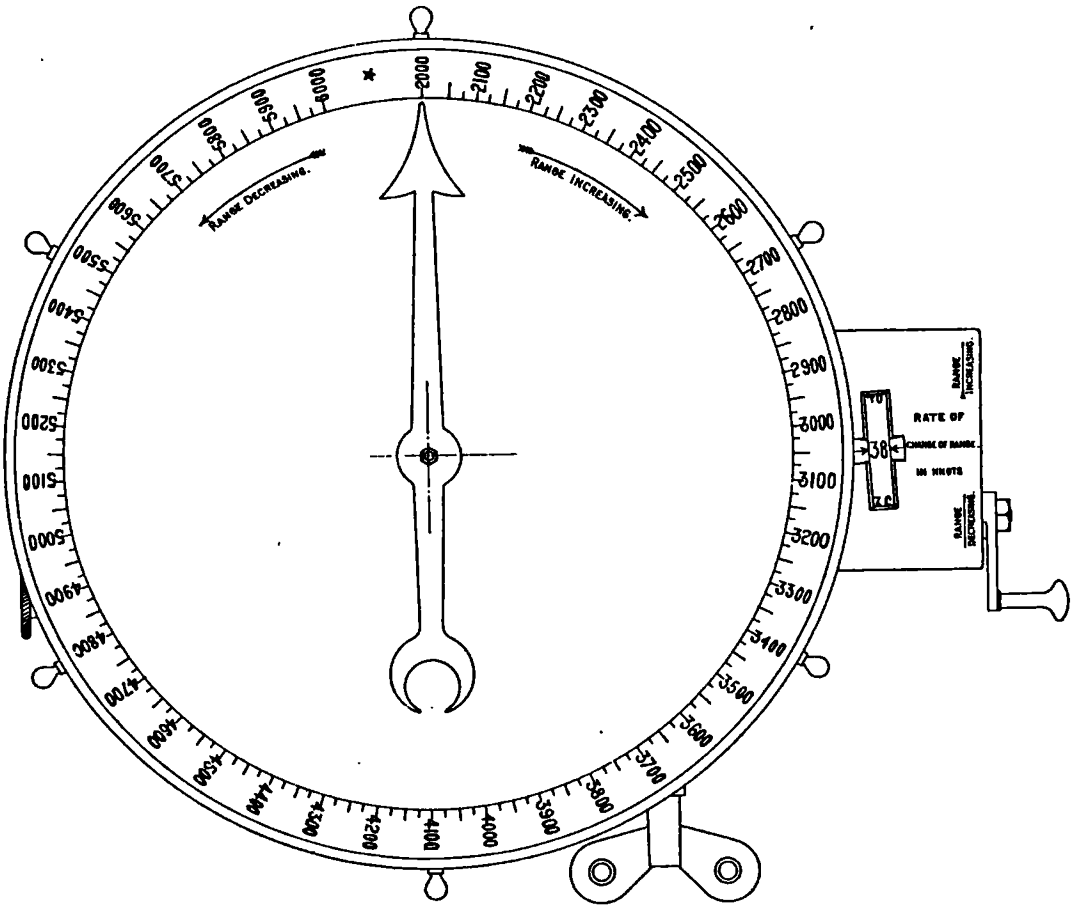
[215] DNO's minute 18 November 1913 in IQ/DNO II, 1913.
[216] 'Quest for Reach', pp.22-3.
[217] Captain H G Thursfield, 'Development of Tactics in the Grand Fleet', Lecture No. I, 22 February 1922 in THU 107, NMM. Attached to the text is a copy of Callaghan's 1913 memorandum stating that 'fire may well be opened at 16,000 yards'.
[218] Also, the maximum range of the German 5.9-inch secondary armament was a long 13,500 metres (about 14,700 yards). Erich Gröner, revised Dieter Jung and Martin Maass, *German Warships 1815-1945, Vol I* (London, 1990) pp.23-8 and 53-7.
[219] On p.93, the firings at *Empress of India* at 9,800 yards are cited as evidence that in 1913 this was regarded as 'very long range'. The footnote does not mention either that 13.5-inch ships fired shell from the old *Royal Sovereigns* with reduced charges, or the intention for *Neptune* and *Hercules* to fire at up to 15,000 yards with full charges: Callaghan memorandum (*op. cit.*).

two requirements. When visibility was good, fire must be opened at long-range (13,000 to 16,000 yards): but, if visibility was poor, at as little as 7-8,000 yards. These expectations had influenced the choice of rate plotting for manual fire control: and, as the following chapters will show, they were also to be important considerations in the decision between the Dreyer and Argo systems.

PLATES FOR CHAPTER 3

PLATE II.

RANGE INDICATOR.



The method of using the instrument is as follows. The Rate of Change of Range having been obtained by Range Finder & Timing or guessed, the instrument is set to that speed.

The Distance having been obtained, the dial face is set with the distance opposite to the pointer, if the relative speeds have been correctly assumed, and if the initial distance was correct the Pointer will continue to shew the distance which should be put on the sight

If the fall of the shot shows that too much or too little change in range is being applied, the rate can be altered.

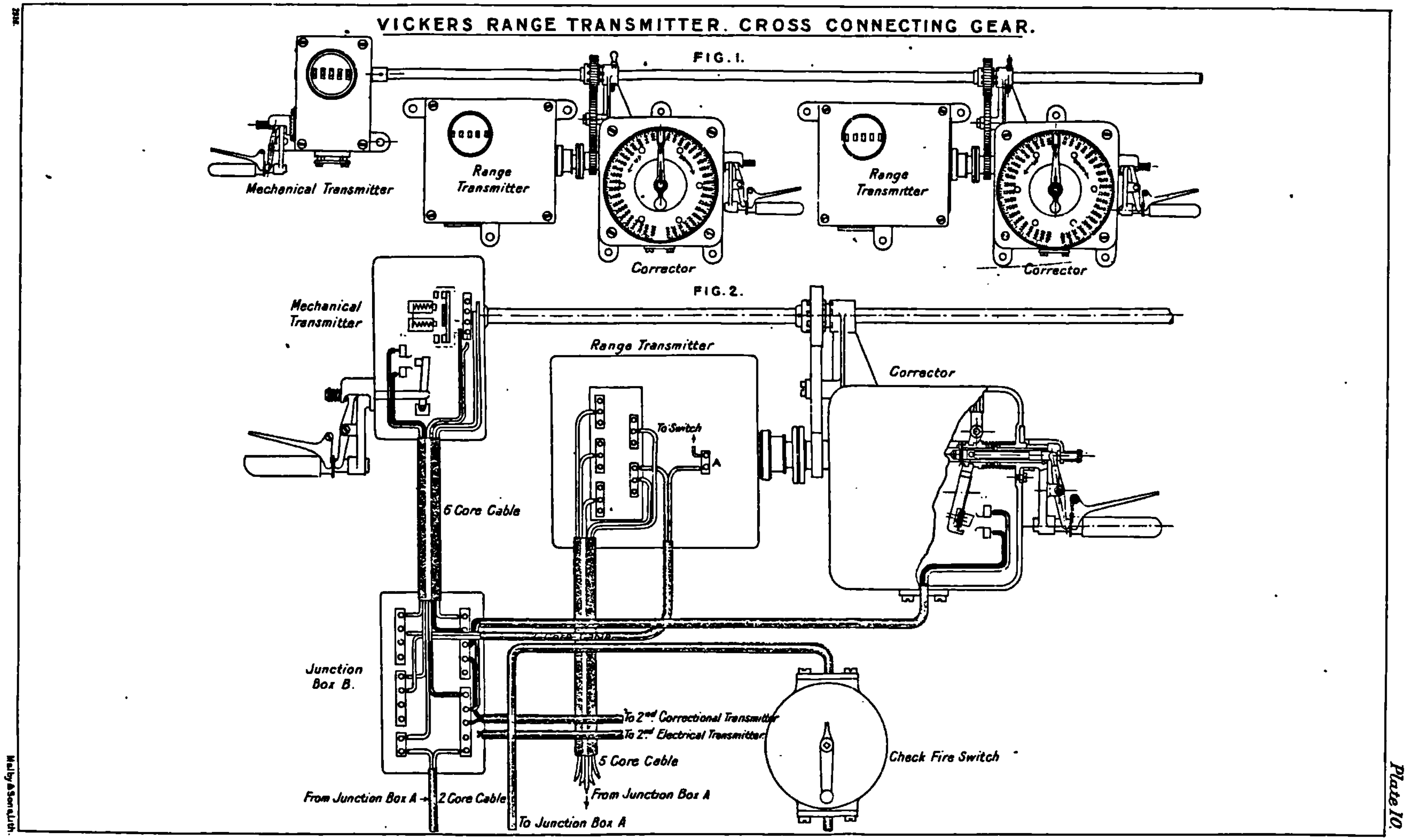
If the fall of the shot shows that the distance is incorrect, the perimeter of the dial is moved round until the correct distance is opposite the pointer; thus the pointer should always stand at the actual distance which is to be passed to the guns and the indicator, the telegraphs and the gun sights should always agree.

4. Range Indicator proposed by Percy Scott

As originally proposed by Scott, the maximum range on the scale was 6,000 yards.

The range-rate calibrations were in knots, even though early Dumaresqs were calibrated in 'seconds to change 50 yards' and rates from timed ranges were more conveniently expressed in yards-per-minute.

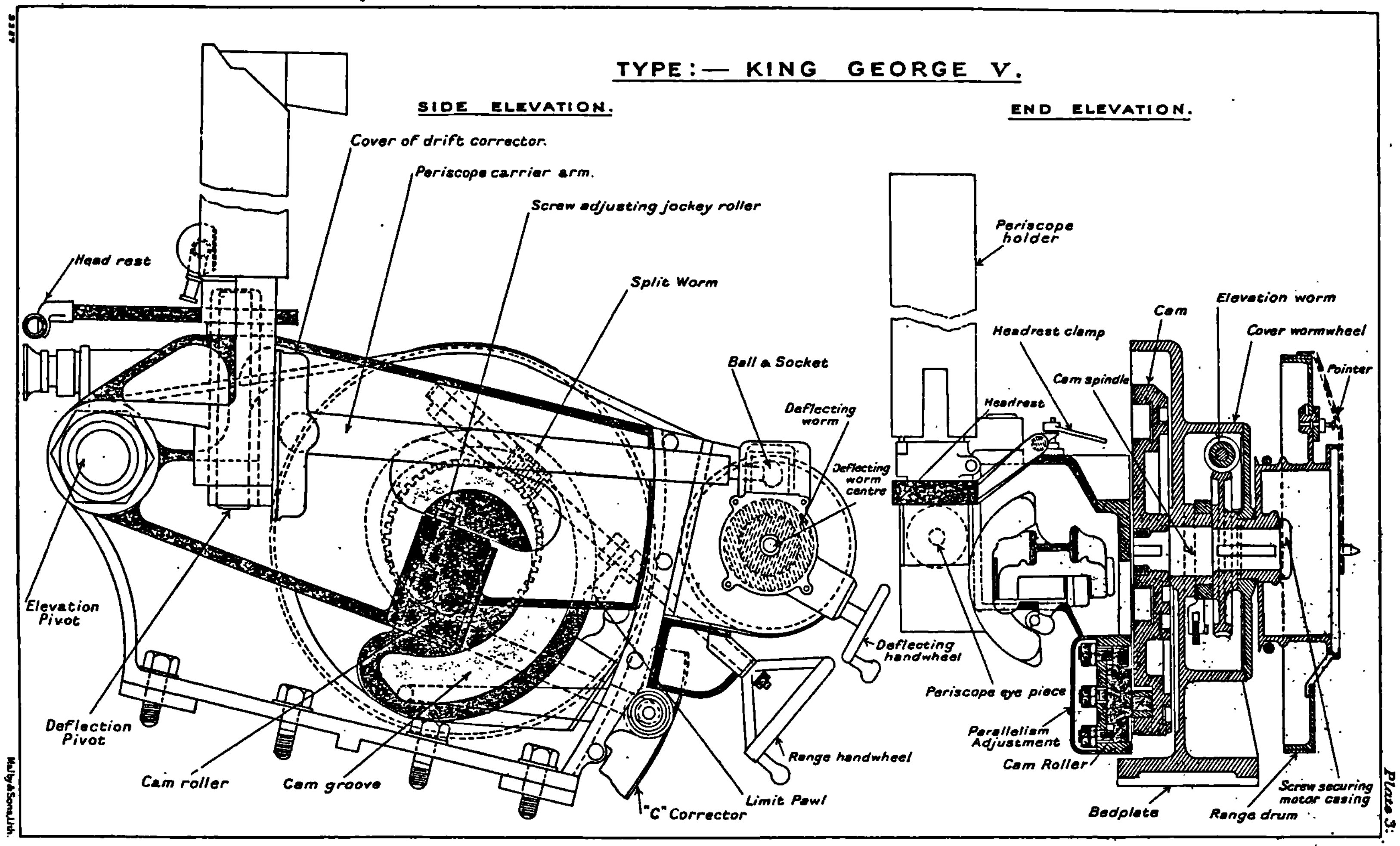
Percy Scott, 'Gunnery Lecture II. Remarks on Long Range Hitting', 15 December 1903 and Plate II in *Gunnery* (privately printed, June 1905).



5. Vickers Cross Connecting Gear

The Mechanical Transmitter was kept in step with the indications of the Vickers Clock.
The Corrector contained a differential which added the correction set on its dial to the range from the Mechanical Transmitter. Thus the transmitted gun ranges could be given different corrections according to the nature of gun.

Admiralty, Gunnery Branch, *Handbook for Fire Control Instruments, 1914*, Plate 10, ADM 186/191.



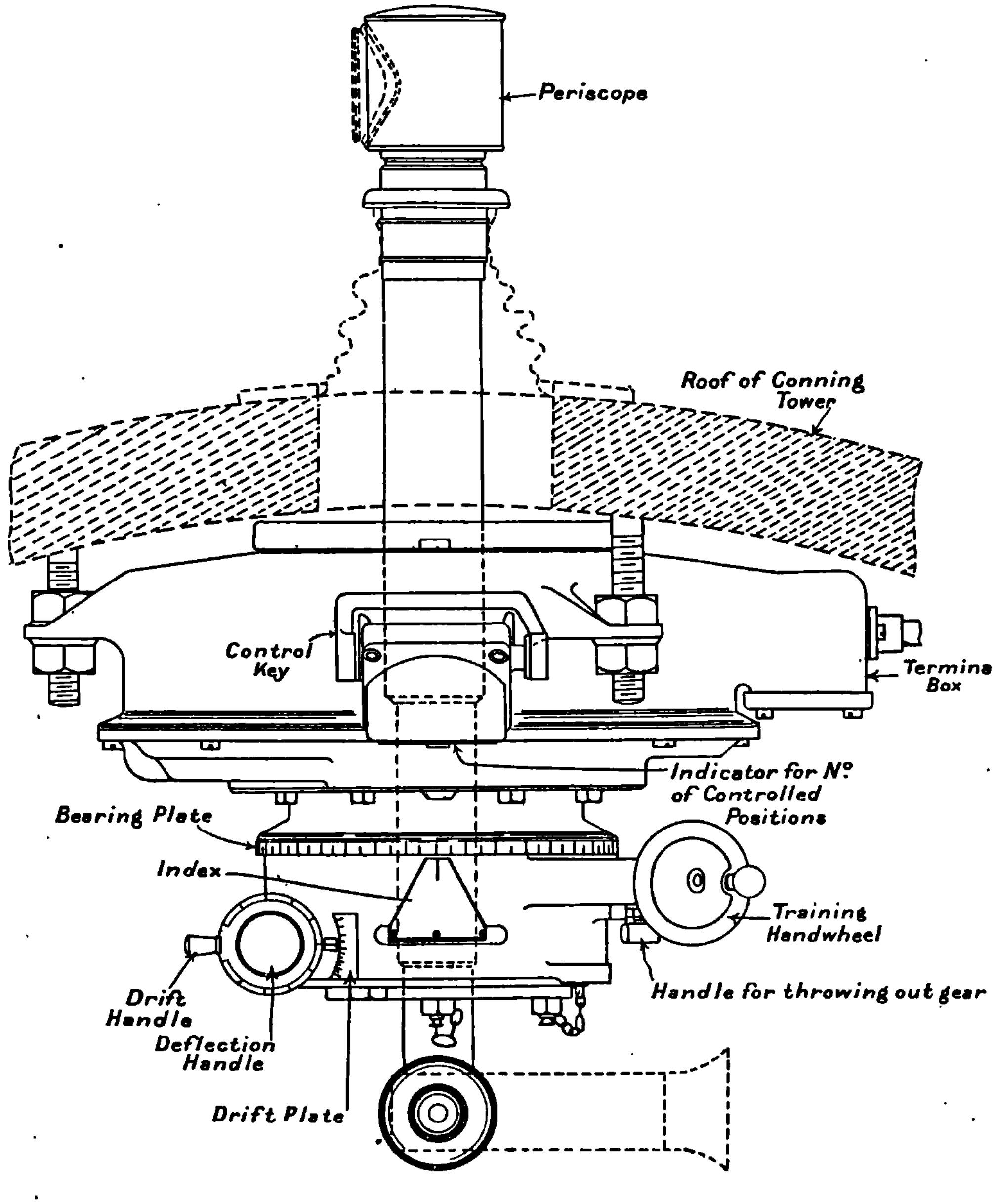
6. Follow-the-Pointer Cam Sight, King George V Class

The casing for the follow-the-pointer receiver motor is to the right of the end elevation.
The "C" Corrector was originally intended to apply ballistic corrections for changes in atmospheric density; it was used later to correct for different natures of projectile.

Gunnery Branch, *The Sight Manual 1916*, p. 6 and Plate 3, ADM 186/216.

EVERSHED'S BEARING INDICATORS

TRANSMITTER WITH PERISCOPE



7. EVERSHED TRANSMITTER

The periscope established the line-of-sight to the target.
A turret was correctly trained when the axes of the guns were appropriately deflected from the line-of-sight to correct for drift and deflection. In the Evershed transmitter, the transmitter (a rheostat) was coupled to the bearing plate. The deflection and drift handles introduced the required angular displacements between the periscope and the bearing plate.
Some transmitters could also be equipped with receiver rheostats and indicators (Plate 8).
Transmitters could also be coupled to telescopes or to the Argo rangefinder mounting.

Admiralty, Gunnery Branch, *Handbook for Fire Control Instruments. 1914*, pp.30-3 and Plate 35, ADM 186/191.

EVERSHED'S BEARING INDICATORS.

GUN SIGHT INDICATOR.

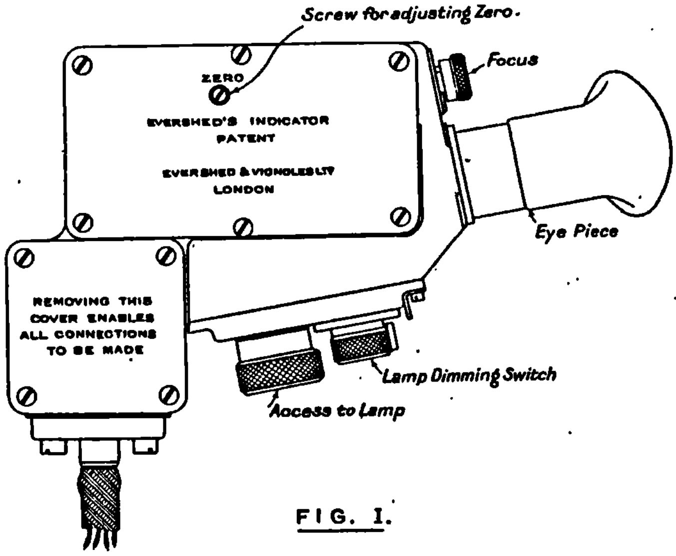


FIG. I.

OPEN FACED INDICATOR.

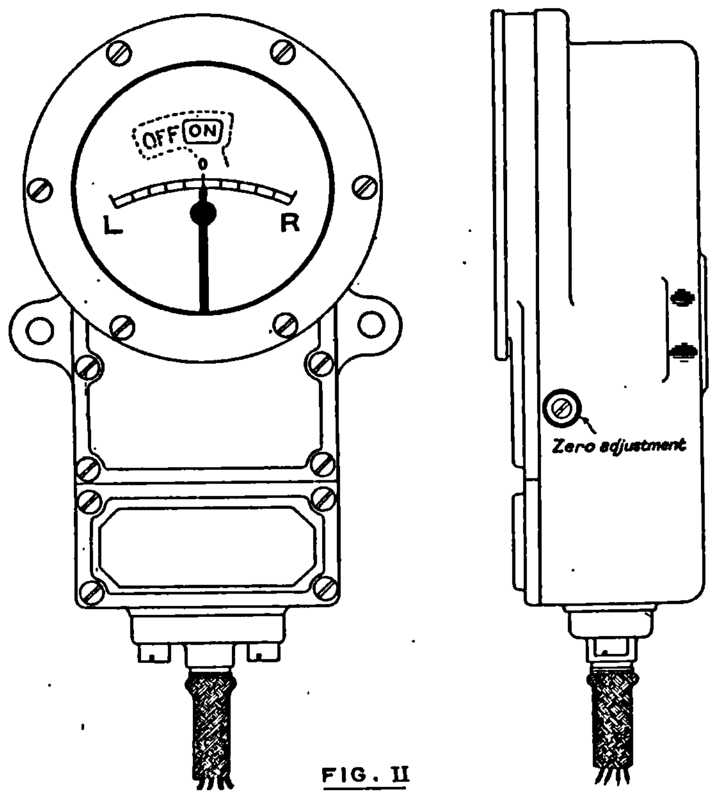
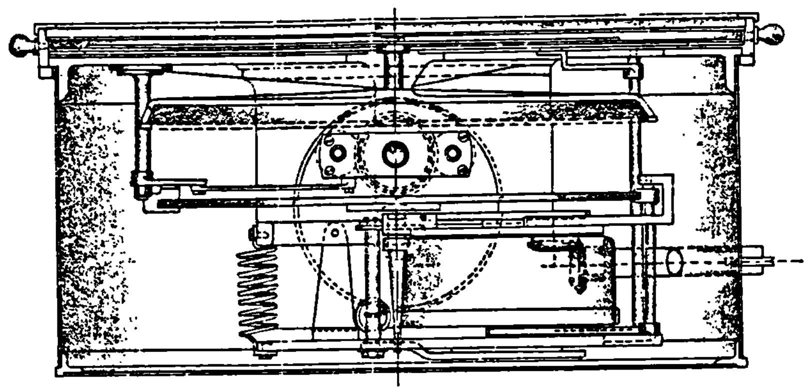


FIG. II

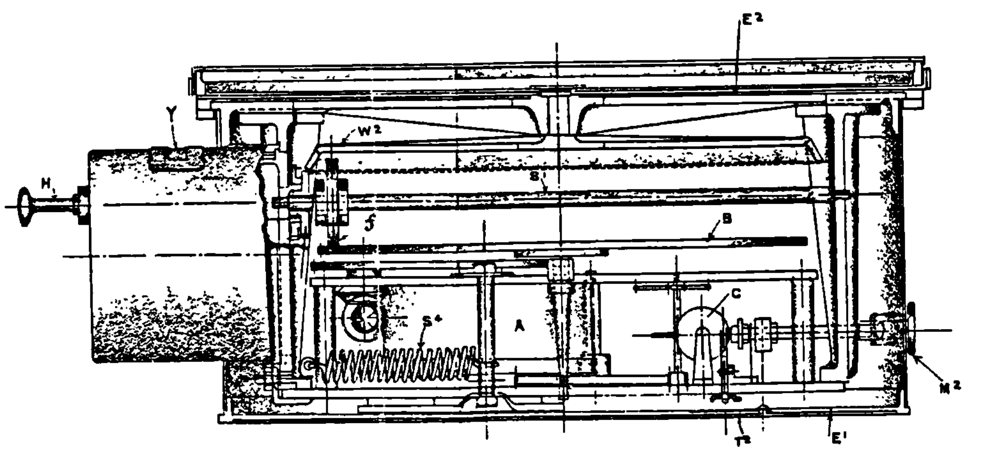
8. Evershed Indicators

Indicators contained a galvanometer needle which indicated ON when the electrical 'bridge' formed by the transmitter and receiver rheostats was balanced. The system was accurate to 1°.
In turrets, the receiver rheostats were geared to the turret trunks.
The gun sight indicator was mounted on the sight telescope used by the turret trainer (the right-hand sight of the left gun). The trainer could view the indicator with his left eye while watching the target through the sight with his right.

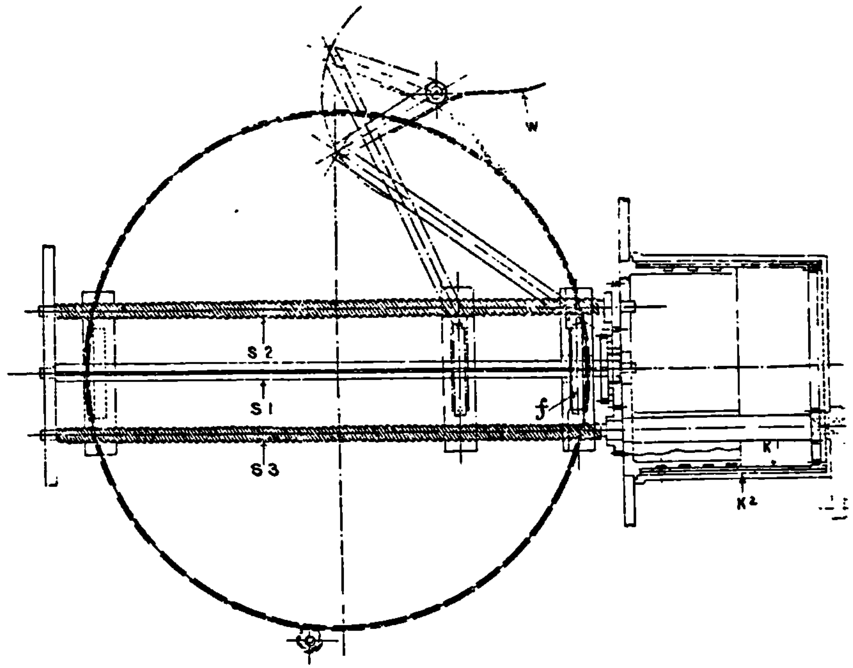
Admiralty, Gunnery Branch, *Handbook for Fire Control Instruments. 1914*, pp.30-3 and Plate 38, ADM 186/191.



VERTICAL SECTION AT RIGHT ANGLES TO RATE DRUM



VERTICAL SECTION ACROSS RATE DRUM



HORIZONTAL SECTION ON PLANE OF SCREWED SPINDLES

9. Vickers Clock: Mechanism

The clock's variable-speed drive was of the conventional form with large disc and small roller. The roller could slide on the slotted shaft mounted diametrically above the disc. Its position was controlled by the carriage running on the parallel pair of threaded rods. These were coupled to the rate handle; thus the rate could be adjusted continuously.

A pinion at one end of the roller shaft engaged with the large crown gear; this gear was pivoted at the centre of the dial and carried the range pointer. The details of the springs powering the mechanism, the governor and the compensating brake are not shown.

Admiralty, Gunnery Branch, *Addenda (1909) to Gunnery Manual Vols. I (Part I) and III*, November 1909, p.54 and Plate XXXVII, NMM.

4

A C and Argo

This chapter addresses two themes. The first concerns the technical capabilities of Pollen's fire control instruments and, in particular, the extent to which, at different times, they could claim to be helm-free (Here, 'helm-free' means that operation is the same whether own ship's course is steady or changing.) The second is the troubled and unusual relationship between the Admiralty and Pollen and his Argo Company: and the personal, financial and political factors which shaped it. Both themes are explored against the convenient time-frame fixed by the four trials of Pollen's gear aboard *Jupiter* (1905-6), *Ariadne* (1907-8), *Natal* (1909-10) and *Orion* (late 1912).

Technical

In February 1900, after witnessing a practice at 1,400 yards (which must, therefore, have been a gunlayer's test), Pollen recalled being 'told that no practice was carried out at any much greater range', and concluding that the short ranges were due to 'the absence of an accurate range-finder'.[1] As Managing Director of the British Linotype Corporation, he was able to use their resources to start development of a two-observer rangefinder. In early 1901, he made his first approach to the Admiralty, submitting only drawings of the machine that calculated ranges from each pair of simultaneously-taken bearings;[2] he also claimed that '...observing to within eight seconds...with telescopic sights...should not be a difficult feat'[3] and that 'important inventions have been made...for

[1] Arthur Pollen, 'The Gun in Battle', February 1913 in Jon Sumida (ed.) *The Pollen Papers 1901 - 1916* (London, 1984) p.308.
[2] Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) pp.78-9. A first patent for a calculating machine (subsequently abandoned) was applied for on 18 July 1900 (p.102).
[3] Even the verniers of precision theodolites, used in land-based surveying, were divided only to 10 seconds

combining the telescope with one or more gyrostats'. His letters were followed by a pamphlet which acknowledged that, with 150 feet between observers, the claimed bearing accuracy could still lead to range errors of 621 yards at 20,000 yards. The pamphlet made no mention of gyrostats,[4] but, like the letter, it proposed that the enemy's position should be plotted manually on a navigation chart, thereby obtaining his speed and course.

> The primary use of this device...would be for tactical and strategical purposes....The secondary use...would be as a range-finder for guns...at ranges hitherto considered impractical at sea.[5]

Thus these sources do not substantiate Pollen's later claim that it was already clear to him that the chart could be used for 'the forecasting of future ranges and the angle of deflection'.[6]

The Admiralty rejected Pollen's proposal but he continued work, principally on the calculating machine; it was probably completed before the end of 1902.[7] He and his engineers then turned to the much more difficult problem of taking and transmitting simultaneous bearings. In 1904, two pamphlets produced in July and December described not just the rangefinder and calculator, but a charting table and clock.[8] A figure from the second pamphlet (Plate 10) illustrates clearly the difficulty of observing bearings with sufficient accuracy.[9] The chart or plot was to be made on a broad paper ribbon moved by clockwork at a speed proportional to the speed of the firing ship, enemy position being plotted manually with the pin sliding on the plotting arm. Own course was traced by a second 'pricker' beneath the pivot of the plotting arm (Plate 11).[10] Since own course could *only* be represented by the straight line at the edge, this was a straight-course plotter. Yet the second patent seems to imply some notion of helm-free working:

> ...the ribbon carrier may be, and preferably is, mounted to turn on a suitable pivot so that it can be swung according to a change of course'.[11]

---

of arc: J A Bennett, *The Divided Circle* (Oxford, 1987) Plates 107 and 229.

[4] *PP*, 'The Pollen System of Telemetry', February 1901, pp.8-13.

[5] Pollen to Selborne, 4 February 1901 in RCAI Claims Files, T.173/91 Part VII, PRO. Excerpts from the letters in *PP*, pp.210-1.

[6] *PP*, 'Gun in Battle' (1913) p.309.

[7] Patent 6,838 of 1902, applied for 20 March, complete specification 22 December.

[8] Patents were also taken out for the bearing transmission system (11,535/1904) and the table (23,872/1904), applied for 19 May and 4 November respectively.

[9] *PP*, 'Fire control and long-range firing: an essay to define certain principia of gunnery...', December 1904, pp.35-7 and 52 and patent 23,872/1904, p.3.

[10] *PP*, 'Memorandum on a proposed system for finding ranges at sea and ascertaining the speed and course of any vessel in sight', July 1904, p.17 and patent 23,872/1904, p.6.

[11] Patent 23,872/1904, p.5.

although this arrangement could not have produced a true-course plot. In contrast, if a figure from the second pamphlet (Plate 12) is compared with Fig. 2.12b, it appears that Pollen may have been thinking of the version of straight-course plotting which depended on a directional reference to hold an initial steady course; however, no such reference (gyroscopic or otherwise) is mentioned in the documents.

Even by July, Pollen was clear that a plot of enemy course could average out the errors in individual observations: although, by December, he claimed, extravagantly, that the range could be 'accurate probably to 1-10th of 1 per cent'.[12] In July, he also described for the first time a 'clock' which was intended both to forecast ranges and transmit them to the guns. However, it was little more than an initial, incomplete concept, since it had dials for setting speeds and enemy course but not for enemy bearing or for ballistic corrections.[13] Nor does the pamphlet contain a single reference to deflection. At about the time of its publication, Pollen was given permission by Vice-Admiral Lord Charles Beresford to seek advice from gunnery experts in the Channel Fleet,[14] after which the December pamphlet shows a greater appreciation of all the factors affecting hitting at long range. It also displays a knowledge of the latest Service instruments, notably the Dumaresq, the Scott/Vickers clock and an appliance by which the 'range may be put upon the sights with great rapidity';[15] this was probably the Vyvyan-Newitt direct sight-setting gear, which was under trial in the Channel Fleet in the last quarter of 1904.[16]

For his own system, Pollen now proposed a 'change of range and bearing machine', though no hints are given of its mechanism. Having been 'set to own and enemy's course and speed', this would keep both range and target bearing and transmit them to dials in the gun positions '[s]o long...as the courses and speeds remain unaltered'. The difference between true and gun range was to be determined by using the two-position rangefinder to measure the distance of the fall of ranging shot. The final element of the system was a separate deflection machine which was 'in the course of design'.[17] In mid-1905, Pollen produced a further pamphlet in which he first named his system 'Aim Correction'. He dropped any idea of 'ranging the splash'. Instead, he

[12] *PP*, 'Fire Control' (1904) pp.54 and 39.
[13] *PP*, 'Proposed System' (1904) pp.18-19.
[14] *IDNS* (*op. cit.*) p.80.
[15] *PP*, 'Fire Control' (1904) p.29.
[16] Captain of *Victorious* to Rear Admiral Second-in-Command Channel Fleet, 7 December 1904 in 'Vyvyan-Newitt, Siemens and Vickers Electrically Controlled Gunsights' in ADM 1/7832, PRO.
[17] *PP*, 'Fire Control (1904) pp.40-41.

proposed that the range and deflection machines would calculate the known ballistic corrections and that bracketing (with single shots) be used to correct for unknowable factors.[18]

JUPITER

Only the rangefinding system and plotter were ready for trials in *Jupiter* from November 1905 to January 1906.[19] Conditions were sometimes severe, but Pollen acknowledged that:

> It has, however, to be stated without any reservation that the instruments have failed to carry out the requirements of the system under weigh...

He blamed the means for training the telescopes and confusion between the transmitted bearings.[20] In fact, as shown in Appendix XII, Note 1 (XII-1), the range accuracy promised so confidently required synchronisation within milliseconds between bearing observations, impossible demands on the observers and the electromagnetic transmission. Manual plotting proved too slow and prone to error. Pollen later admitted that: 'Our first experiment was a complete failure' and that:

> Now that I know the difficulties involved, I can realise that no crazier scheme was ever put forward.

However, Pollen also claimed that lack of time and money before the trials prevented the development of '[g]yroscopic correction, a plotting table adjustable for the turn and the change of range and bearing machine'.[21] He blamed the Admiralty for advising that gyroscope control 'was not indispensable' and for being unwilling to fund 'prolonged and...costly experiments'.[22] In fact, after the brief reference to gyrostats in 1901, they are not even mentioned again until improvised experiments in *Jupiter* for yaw correction. Furthermore, Pollen had no settled scheme for a helm-free plotter: and, while the Admiralty were prepared to purchase a range-clock, Pollen had been unable to develop it in time.

Undaunted, in February 1906 Pollen suggested:

[18] *PP*, 'A.C.: A Postscript', mid-1905, pp. 56-63.
[19] *IDNS*, pp.85-7.
[20] *PP*, 'Jupiter Letters': III, January 1906, p.83 and IV, 2 February 1906, p.88.
[21] *PP*, 'Gun in Battle' (1913) pp.309-11.
[22] *PP*, 'Notes, Etc. on *Ariadne* Trials', April 1909, pp.212-3. See also *PP*, 'The Quest of a Rate Finder', November 1910, p.265.

> ...that as the final development of the two-observer system must take some time, the Aim Corrector System should be tried with one-observer range finders in the meantime.[23]

by which he meant the new Barr and Stroud 9-foot instrument. The unworkable two-observer system was soon dropped and, with the help of Harold Isherwood[24], the A C system was transformed into a gyroscopically-controlled rangefinder mounting transmitting simultaneous ranges and bearings to an automatic plotting table. The description of the 'One Observer System of Charting' submitted in June 1906 also included a 'change of range' machine which could be set for 'yaw correction' and transmit elevation and deflection angles, preferably direct to the gun sights;[25] however, no range clock of any description was made at this time[26] nor was one included in the agreement concluded in October for the supply of a prototype mounting, transmission system and plotter. In the same month, Pollen and Isherwood applied for a patent[27] on the dual-gyroscope directional reference (Plate 13 and XII-2). In a remarkably short time, by November 1907, the trial gear were ready for installation in *Ariadne*.[28]

ARIADNE

On 3 August 1907, in writing to the new DNO, Pollen claimed that '...it would not be difficult...to make [the clock] calculate and transmit the deflection as well as the range....'.[29] In the same month, he prepared lecture notes which described the complete Aim Correction system as it might be installed in *Invincible*. The rangefinder pedestal was trained by 'a gyroscopically-controlled electric drive, which...consequently neutralises... changes of course due to the yawing of the ship'. Ranges and bearings were transmitted to the 'charting table' and plotted automatically. Enemy speed and course were then set on the change of range machine (this also kept the target bearing) and on a separate deflection machine.[30] Range and deflection were then transmitted from the machines to

[23] *PP*, 'Jupiter Letter IV' (1906) p.86.
[24] Their first joint patent (13,082) was applied for on 6 June 1906. However, in his evidence to the first RCAI hearing, Isherwood said that his association with Pollen began in 1902: RCAI Minutes of Proceedings, T.173/547 Part 3, p.25.
[25] Pollen to the Secretary of the Admiralty, 18 June 1906 with 'One Observer System of Charting' 15 June 1906 in T.173/91 Part VII.
[26] 'No clock was ever made until the Natal clock'; Pollen's counsel to the RCAI, T.173/547 Part 7, p.37.
[27] 23,846 applied for 26 October 1906.
[28] *IDNS*, p.123.
[29] Pollen to Bacon, 3 August 1907 in T.173/91 Part VII.
[30] The means of generating deflection were evidently undecided.

the automatically-set sights; and both machines worked 'on the assumption that both ships are maintaining a steady course and a level speed'.[31]

After the *Ariadne* trials, Pollen printed a detailed description of the rangefinder mounting, the complex, synchronous transmission system and the plotter. The mounting was trained by a pair of electrically-activated counter-rotating clutches; as might be expected (XII-3), the mounting tended to 'hunt' around the correct training angle, Pollen himself stating that the observer was 'relieved...of everything except a rhythmical motion for the training by the gyro correction'.[32] As in *Jupiter*, the plotter worked on the straight-course principle, but the plotting arm and the pencil for plotting enemy course were now positioned automatically using the ranges and bearings transmitted from the rangefinder. These bearings were relative to the mean course as defined by the pair of gyroscopes in the mounting (XII-4). If the course altered by more than 12½°, both gyroscopes were clamped parallel to the keel-line and not released until the new course was established;[33] thus plotting was suspended while the gyroscopes were clamped,[34] and the type of plot produced was like that shown in Fig. 2.12c. The *Ariadne* plotter was yaw-free, but not helm-free.

The criterion for success in the trials, which had been agreed in October 1906, was that, two minutes after the target range had fallen to 8,000 yards, the range should be predicted to within 80 yards for a further three minutes.[35] In the absence of an A C clock, the enemy speed and course from the plot were to be set on a Dumaresq, the rate then being applied to a Vickers clock. These demanding requirements were tested on 11 and 13 January 1907 in Torbay, where the courses could be accurately surveyed.[36] Pollen declared that his gear had come 'successfully through the Torbay tests for exactness in results'.[37] In fact, his own printed notes (reproduced in Appendix XIII) show that, out of five runs, four obtained the enemy course to within 70 yards of the surveyed results, but it

[31] *PP*, 'An Apology for the A.C. Battle System; being notes for a lecture to the War Course College, Portsmouth', printed December 1907; see especially pp.140 and 145-150.
[32] A H Pollen, 'Notes on Charts, made before Christmas, sent to Admiral Wilson' pp.2-3 in *Notes, Correspondence, Etc. on the Pollen A.C. System installed and tried in HMS Ariadne*, December 1907 - January 1908 in DRAX 3/1, CC: but not in the abridged version in *PP*, pp.159-171. For the transmission system and clutches, see also patent 14,415/1908.
[33] 'The Pollen Aim Corrector' in *Notes, Correspondence on A.C. (op. cit.)* but not in *PP*.
[34] Professor C V Boys to Pollen, n.d. but November 1912 in T.173/91 Part II: see *IDNS*, p.230.
[35] 'Pollen Aim Correcting System. Points discussed at an interview with Mr Pollen...' with Ewan Macgregor to Pollen, 29 October 1906 in T.173/91 Part VII.
[36] *IDNS*, pp.128-9
[37] *PP*, Pollen to Wilson, 24 January 1908, p.166.

is not certain that, even then, the Dumaresq and clock correctly predicted the range. Pollen declared:

> It was no part of the plan of the designers to consider chiefly facilities for getting the data off the chart with rapidity; it appeared that this was a matter in which only experience could indicate the best method.[38]

Yet the complete A C system itself depended on setting the clock from the plotted results.

In the Torbay trials, the maximum rate was 'not 500 yards a minute' but on 15 January, in 'the only experiment made at sea, there was no change of range at all'.[39] In such conditions, the A C gear must have given accurate results but, although Wilson's report has not been found, there can be no doubt that he recommended rejection in favour of manually-worked alternatives. From Pollen's subsequent riposte, it is clear that Wilson also criticised the performance of the A C equipment. Most seriously:

> (a) A change of course throws the instruments out of gear. An operator has to stop the gyroscopes... and release them again when the ship is on her new course.
> (b) The gyroscopes creep....
> ....
> (e) The instruments were shown to be unreliable.

The first point was perfectly valid, despite being rejected by Pollen because 'the gyroscopes, after...a change of course, automatically select and keep the new course'. Respecting the gyroscopes, Pollen unwisely asserted that 'the gyroscopes do not and cannot creep',[40] particularly since he had already admitted that:

> ...in the experiment carried out by Admiral Wilson on the 12th [December] with the ship anchored...it was found that the creep of the gyros was...some 2 or 3 degrees in 4 or five minutes.[41]

Whatever the extent of the creep at sea, the dual-gyroscope design, despite its many ingenious features, was superseded within the year. Finally, as for general unreliability, Pollen claimed that 'the gear...never once broke down, or failed in a single particular'.[42] Yet, only one year later, he admitted that the *Ariadne* gear was not ' in all respects fitted for its purpose' and to defects in the plotting devices.[43] While Wilson's report probably exaggerated the gravity of the defects, it is unlikely that the A C gear was yet fit for service. And, as Pollen admitted in private correspondence:

[38] A H Pollen, 'Notes of the Torbay Trials of the A.C. System', in *Notes, Correspondence on A.C.* (*op. cit.*) but not *PP*. The *Ariadne* plots gave 'substantial accuracy in from one to 2½ minutes': Boys to Pollen (1912).
[39] Pollen to Wilson (*op. cit.*) p.165.
[40] *PP*, Pollen to the Secretary of the Admiralty, 25 March 1908, p.235.
[41] 'Notes on Charts' (*op. cit.*) p.4
[42] Pollen to Secretary, 1908 (*op. cit.*).
[43] Pollen to the Secretary of the Admiralty, 5 January 1909 in T.173/91 Part II.

The Ariadne thing...is...of course...exceedingly incomplete as a fire control system... and I reckon it will take me a full year to get the other instruments...running to my satisfaction.[44]

After the *Ariadne* trials, Pollen received further funds to continue development. In January 1909, he announced:

...the completion of the drawings of the entire system....The mechanical devices we shall employ...have all, during the last twelve months been exhaustively tried and proved to be reliable.... The system is now no longer in a tentative stage.

The principal instruments of the 'Pollen A C Battle System' were as before. In the rangefinder, the dual gyroscopes had been replaced by a single, continuously-running, air-driven gyroscope which also used air jets to correct for precession.[45] However, the gyroscope was still clamped during any substantial course change,[46] so the mounting remained only yaw-free.

Pollen's description of the system indicates that the charting table was being completely redesigned to plot on both broadsides; it was also intended to place marks at one minute intervals along the enemy's course as an aid to measuring his speed. While plotting on moving paper is mentioned, the preference was that:

Our position on the Charting Table will be driven instead of the paper.
... The Chart will be rotatable about an adjustable centre at the moment of change of course [by own ship]. The extent of the turn can be controlled by the rangefinder or by hand.[47]

Just such an adjustable centre (a pin sliding in a carrier pivoting about own-ship's pencil) was described in the contemporary patent for the manual course plotter, but, before a turn even commenced, the pin had to be positioned according to the *expected* radius of the turn.[48] This scheme evidently proved unworkable, since Pollen stated subsequently that the table as originally designed could represent own course only as rectilinear.

To plot a turn, or to plot during a turn, was consequently impossible. We had long been of opinion that this was a grave omission.

To justify the latter claim, he harked back to his 1904 patent, even though he had to admit that it 'would certainly not have given us the results we wanted'.[49] He blamed 'the

[44] *IDNS*, p.138.
[45] 'The Pollen A.C. Battle System' with Pollen to Secretary, 1909 (*op. cit.*). For the gyro, see patent 11,795/1909 applied for with complete specification 19 May.
[46] Draft letter concerning "Natal" pattern mountings with proposal 'R-F Bearing transmitter', 1911 in DRAX 3/4.
[47] 'A.C. Battle System' (*op. cit.*)
[48] Patent 5,031/1909 applied for 2 March, pp.3 and 5-6 and Figs. 3-5.
[49] *PP*, Pollen to Admiral Colville, 1 July 1910, pp.245-6.

cry, that the gear was too complicated already' for the original *Natal* plotter being on the straight-course principle:[50] but in fact there is nothing to show that, prior to the 1909 trials, Argo had any worked-out scheme for true-course plotting.

The 'change of range and bearing machine' as described in January 1909 was set with own speed, enemy's speed, course, range and bearing, and the time of flight. It generated and transmitted gun angle and deflection to automatic sights. Its settings could be corrected if they differed from the plotted values: but spotting corrections were transmitted directly from the spotters to the sights.[51] No specific mention is made of change of own course. However, a description of the 'range and deflection clock', which was probably written a little earlier, stated:

> Any dial can be altered while the Clock is running including own speed. If own Course is changed it has the effect of altering the angle between Target Course and Own Course so the alteration due to the change of Own Course is made on the Target Course Dial.[52]

Clearly, Pollen had given the impression that the clock could keep the range and bearing through a turn.

NATAL

No detailed description has been found of the straight-course plotting table which, with the rangefinder mounting and transmission equipment, were delivered to *Natal* on 21 September 1909. However, as explained in XII-5, its general arrangement resembled that of the patented manual plotter (Plate 11), though it plotted the transmitted ranges and bearings automatically. In the first trials, the equipment impressed the Captain of *Natal*, despite a 'few minor mechanical difficulties'.[53] However:

> Captain Ogilvy, almost as soon as the gear was installed...pointed out to us that the military importance of plotting during a turn seemed to him to be overwhelmingly critical... He urged us therefore to ignore all the complication objections and adapt the table forthwith'.[54]

By 15 January 1910, Pollen and Isherwood were able to submit a provisional patent specification for true-course plotters. They claimed widely for various outline designs, but

[50] *PP*, 'Quest of Rate Finder' (1910) p.265.
[51] 'A.C. Battle System'.
[52] 'Fire Control. An Essay by Captain C. Hughes-Onslow RN', Royal Naval War College, n.d. but 1909, PLLN 1/5, CC. For the influence of assumed fire control capabilities on the decision to built the *Lion* class battlecruisers, see John Brooks, 'All Big Guns: Fire Control and Capital Ship Design 1903-1909' in *War Studies Journal*, Vol. I, Iss. 2, p.45-50.
[53] *IDNS*, p.172.
[54] Pollen to Colville (*op. cit.*) p.246.

the only arrangement described in the complete patent specification (Plate 14)[55] was similar to that of the *Natal* table after it had been modified for true-course plotting. The moving plotting point was now fixed at the centre of the table, while the paper was driven from below by a pair of wheels, one on either side of the fixed plotting point. In the *Natal* table (unlike the patented design) the driving wheels were provided with short spikes, while the paper was pinned to a wooden board of a weight sufficient (it was hoped) to give these 'prickers' sufficient purchase. When the table was returned to *Natal* in early May 1910, it had also been fitted with its own gyroscope; by following its directional indication, an operator set course changes manually.[56] The mounting must have been modified at the same time to transmit target bearings relative to ship's head, as required to position the enemy plotting arm correctly. The mounting's own gyroscope continued to stabilise it against yaw while the course was steady: but, when it was changing, the true-course plot depended on the rangetaker's unaided skill in keeping on the target.

Meanwhile, the long-delayed Argo clock had finally been completed in January 1910 and delivered to *Natal*.[57] Two early clock patents from 1906 and 1908 had described mechanisms employing linkages which, by forming a triangle of velocities, obtained virtual course and speed;[58] some clock drawings seen by a naval delegation to the Linotype works in June 1907 were presumably based on these principles, but: 'The manufacture was not begun at this time of the finished clock'.[59] In contrast, by July 1909, work was well advanced on what was later called the Argo Clock Mark I.[60] The subsequent patent shows that it too relied on a 'simulacrum' of virtual course, now derived by adding together the components of virtual course along and perpendicular to own course (Plate 15 and XII-6). These components were generated by variable speed drives, their discs being driven by a speed-regulated electric motor.[61] A variable speed

[55] Patent 1,111/1910 applied for 15 January, complete specification 12 August.
[56] Pollen to Colville, p.247-8. Patent 1,111/1910 , p.8 and Fig. 8. The table's gyro was probably the same as that used in the rangefinder mounting: Isherwood to the RCAI, T.173/547 Part 3, p.25.
[57] Pollen told the RCAI that the clock was delivered in April (T.173/547 Part 2, p.64 and Part 15, p 38) states; but it may have been February (*IDNS*, p.198).
[58] Patent 595 of January 1906 was subsequently abandoned but the description in *IDNS*, p.82 indicates that it was similar to 2,497/1908.
[59] Pollen before RCAI, T.173/547 Part 14, p.82. This contradicts *IDNS* p.121 which apparently cites the same source, Part 14 for 1 August 1925 being also labelled Day 9. Dreyer, a member of the party, denied seeing any clock drawings: T.173/547 Part 16, p.39.
[60] Dreyer before RCAI, T.173/547 Parts 16, pp.39-40 and 17 pp.58-9.
[61] Patent 360/1911 applied for 5 January, Figs. 3 and 4 and pp.3-4 (the complete specification of 28 June was identical).

drive of very similar design was also shown in the patent for the true-course plotter.[62] These mechanisms are significant as the first Argo drives based on a disc, a ball and a pair of rollers (Fig. 4.2). However, at this stage of development, the rollers were stationary so, to change the rate, the ball had to be forced sideways against sliding friction at its points of contact with disc and rollers.

After preliminary experiments from 24 May and 9 June 1910, the actual 'Aim Corrector Trials', conducted by a committee presided over by Rear-Admiral S C J Colville, followed between 16 and 29 June.[63] They were intended to compare *Natal's* automatic plotting with manual plotting of true and virtual course by, respectively, *Lord Nelson* and *Africa*: and to verify 'the general suitability and reliability of "NATAL'S" installation for use in action'.[64] Unfortunately, even the preliminaries established that:

> ...in their present form, the instruments are neither reliable without more skilled attention than they can get in a newly commissioned ship[65] nor in many of their unessential details suited to ship or sea conditions.....
> That many of elements...need radical alteration has already been recognised...in the case of the rangefinder mountings....The case...is more obvious and stronger in the case of the other instruments.[66]

Electrical terminals and 'rubbing contacts' (on which the relays throughout the system depended) failed.[67] Pollen had to accept that the rangefinder mounting was still 'seriously defective', both the gyro and its relay proving unreliable. The worst problems were with the hastily-modified plotter. The pricker wheels lost their hold on the wooden board; both board and table-top had warped, but also the weight of the board caused it to 'take charge' if there was any motion on the ship. These sudden movements also broke the already temperamental plotting pens.[68] The table's gyroscope wandered. And the minute marks along the enemy course were little help in estimating enemy speed, because they were made automatically, whether or not the rangefinder had a good 'cut'.[69]

[62] Patent 1,111/1910 Fig.6 and pp.7-8. In the plotter, the drive generated the linear movement of the paper at a rate proportional to own speed.
[63] *IDNS*, p.202.
[64] Admiral W H May, 'Aim Corrector Trials', 31 May 1910, DRAX 3/3.
[65] *Natal* had recommissioned before the beginning of the new trials (*IDNS*, p.202) but, while she had a new Lieutenant (T), Reginald Plunkett, she retained the same Lieutenant (G), Ralph Eliot: *The Navy List*, June 1910.
[66] *PP*, Pollen to the Secretary of the Admiralty 17 June 1910, p.253.
[67] Report by Lieutenant R Plunkett of *Natal*, 4 July 1910, p.2 in DRAX 3/3.
[68] Pollen to Colville, pp. 245 and 248-9. Pollen to Director of Navy Contracts, 25 November 1912 in T.173/91 Part VII. *PP*, 'Quest of Rate Finder' (1910) p.265-6.
[69] Plunkett's report (*op. cit.*) pp.4-5.

Except for an adjusting nut working loose, the clock was reliable but 'the backlash is excessive' and, functionally, it was far from satisfactory. If wrongly set, its range and bearing could not be altered without stopping it and disconnecting the drive screws. For the same reason, there were no means during a turn of applying the large change in the target bearing relative to own course.[70] In any case, the variable speed drives were 'not capable of [driving] while the speed was being altered'.[71] Thus the design of the Argo Clock Mark I restricted it to steady-course working; it was in no sense helm-free.

Admiral Colville's committee concluded that:

> The installation as at present fitted in "NATAL", and as tested in these trials [*sic*] is unsuitable and unreliable for use in action.

Yet they recommended the adoption of the rangefinder mounting (which was already on order) and the 'improved model [clock] as proposed by the makers'. They decisively rejected both forms of manual course plotting but proposed new trials of the A C automatic plotter when 'further developed'.[72] The Admiralty, however, decided to reject the plotter outright; but they also invited Pollen to submit 'detailed designs of an improved and reliable clock' which could 'transmit to Follow-the-Pointer sights with unequal graduations'. They also informed him that the drum-type indicators in *Natal's* turrets had failed to maintain synchronism.[73] In reply, Pollen confirmed that:

> We are already engaged in re-designing the gear, and our present intention is to rebuild it in its entirety....we shall, so soon as the range finder mounting and indicator drawings are complete, put the clock in hand before any other devices.[74]

Meanwhile, by 2 August, Lieutenant Plunkett of *Natal* was already experimenting with time-and-range plotting using the Argo plotter, while the method was used successfully in her Battle Practice on 16-18 August. Isherwood wrote to Plunkett: 'I am interested to hear that you are trying "Time and Range" plotting...',[75] while Argo personnel may have plotted range rates (though not dual rates) while aboard *Natal*.[76] By November, Pollen conceded that, when used with the Argo mounting, dual-rate plotting

[70] Pollen to Colville, p.249 and 'Quest of Rate Finder' (1910) p.268. See also IX-6.
[71] Argo Company, 'Memorandum', 6 May 1913 in T.173/91 Part II.
[72] Colville Committee, Enclosure with letter to C.-in-C. Home Fleet, 1 July 1910 in DRAX 3/3.
[73] Secretary of the Admiralty to Argo, 19 August 1910 in T.173/91 Part VII.
[74] Pollen to the Secretary of the Admiralty, 25 August 1910, in T.173/91 Part VII.
[75] Isherwood to Plunkett, 11 August 1910 and Reginald Plunkett, 'Notes on Plotting', n.d. but after Natal's 1910 B.P., both in DRAX 3/3. Excerpts from *Natal's* log, ADM 53/23982 courtesy Prof. Sumida.
[76] Pollen before RCAI, T.173/547 Part 2, p.21.

was 'a good alternative means of getting and keeping rate - alternative, that is, to straight line plotting'.[77]

ORION

Pollen and Plunkett continued to correspond privately while *Natal's* table was modified for semi-automatic dual-rate plotting.[78] Although unsuccessful,[79] the experience must have been useful for the dual-rate plotter which Argo supplied as part of the system for trial in *Orion*. It was delivered in early 1912[80] and patented in the following October (Plate 16).[81] In this table, the complex synchronous transmission system was replaced by much simpler step-by-step gear. However, the receivers still used counter-rotating electromagnetic clutches (Plate 17) to drive the plotter's pencils.[82] As might be expected (XII-7), these were never entirely satisfactory[83] and, in 1918, the Phillpotts committee found that the 'magnetic clutches...fitted in the plotting table, in H.M.S. "ORION" have given considerable trouble at times'.[84]

Before the end of 1910 (perhaps for the *Natal* trials) the Argo mounting had been fitted with a variable speed power training drive; thus the position of the controlling lever gave a direct indication of the bearing-rate. Pollen then proposed that, if a similar drive were attached to the rangefinder adjustment head, range-rate could be obtained directly.[85] This required a continuous 'cut', the very opposite of the normal method of working a coincidence rangefinder. Lieutenant J C W Henley, who replaced Dreyer as the DNO's assistant responsible for fire control, wrote privately to his predecessor:

> Mr. P. has tried to push this forward into the 45 sets several times but we have opposed it as absolutely impractical.[86]

Even so, Pollen persisted and the power-cut device was included in the *Orion* trials, but it did not prove satisfactory.[87]

[77] *PP*, 'Quest for Rate Finder' (1910) p.269.
[78] Pollen to Plunkett, 22 February and 30 March 1911 in DRAX 3/4.
[79] Draft letter by Plunkett in DRAX 3/3 n.d. but 1911 after delivery of new parts for the *Natal* table.
[80] *IDNS*, p.222
[81] Patent 23,351/1912.
[82] Patent 7,383/1911.
[83] F C Dreyer and C V Usborne, *Pollen Aim Corrector System, Part I: Technical History and Technical Comparison with Commander F C Dreyer's Fire Control System*, February 1913, pp.11 and 34, P.1024, AL.
[84] Phillpotts Committee, 'Report of inspection at York of Pollen Fire Control System', n.d. but 1918, p.2 in DRYR 2/1.
[85] Pollen to Henley, 9 December 1910 in T.173/91 Part VII. Patent 362/1911, applied for 5 January.
[86] Henley to Dreyer, 24 July 1911 in DRYR 2/1.
[87] *Technical Comparison* (1913) (*op. cit.*) p.12.

The production rangefinder mountings only required receivers which could display ranges and bearings, and Argo were able to adapt their original synchronous transmission switches to control arrays of lamps, each lamp projecting one transmitted digit onto a ground-glass screen.[88] In July 1911 (two months before the contracted date) Henley inspected the prototype of the improved design.

> The Training Control is excellent and the Air Gyro is satisfactory but his [Pollen's] mechanical Clutch relay between Gyro and Mounting gives a jerky motion of about ¼° each way. An electrical relay which we tried however improved this enormously.[89]

In the production mountings (Plates 18 and 19), the clutches were finally abandoned in favour of a sophisticated electric relay; this increased the restoring torque delivered by the training motor in three steps as the mounting deviated further from its correct bearing. By February 1912, the first 15 sets had been delivered, another 10 being in manufacture. These retained the air-driven gyroscope, which could only stabilise the mounting against yaw and small course alterations up to 15°. In the remaining 20 sets, it was replaced by an Anschütz gyrocompass receiver which could maintain the directional reference even during large course changes.[90] Thus for the first time these final models were helm-free.

In principle, to keep on the target the rangefinder operator had only to set the power training lever to correspond with the target compass bearing rate. He then used his right hand both to elevate the rangefinder and adjust the cut. With the failure of the power-cut device, all this proved too much and the mounting was modified for a separate trainer, who would also have been better able to correct for wander by the gyros and any residual hunting by the electric relay. Nevertheless, the conclusion after the *Orion* trials was that:

> The arrangements for training are very good and are universally liked....
> With these alterations [for a separate trainer], the instrument is suitable for service use and is a decided improvement on the Barr and Stroud Mounting.[91]

However, this level of satisfaction appears to have been short-lived.

> The 45 sets...ordered had the Argo Gyro fitting in them, but except when first installed were never used as they proved unsatisfactory and were never incorporated in the Admiralty Fire Control System.[92]

[88] Patent 14,302/1911. For electrical details of the transmitters (which are similar to those in the patent 14,415/1908) see *Annual Report of Torpedo School 1912* pp.75-7 and Plate 40, 109 M 91/ART2, HRO.
[89] Henley to Dreyer, 1911 (*op. cit.*).
[90] Admiralty, *Handbook of the Argo A.C. Range-Finder Mounting 1912,* 18 October 1912, PLLN 1/3. *IDNS,* pp.213-4.
[91] *Technical Comparison* (1913) p.34.
[92] Untitled summary of the Admiralty's case in DRYR 2/1. See also similar statements in 'Answer to the Statement of the Claimant's Case', 25 July 1925, 'Outline of the Admiralty Case', n.d. and 'Claimant's

Perhaps this refers only to the mountings with the air-driven gyros. While, as late as 1921, most ships still retained their Argo mountings,[93] the Anschütz gyrocompass installations had long since been replaced[94]. However, even if gyro stabilisation had been disabled in all the surviving mountings, the efficient power training gear was almost certainly still in use.

Isherwood next turned to the new clock. Starting from the earlier type of variable speed drive, his inspired innovation was to mount the rollers in a sliding carriage (Fig. 4.1, Plate 20 and XII-8); thus the rate could be changed with minimal force and without disrupting the rolling friction between the ball and the disc and rollers.[95] On 15 May 1911, Argo submitted to the Admiralty a proposal for 'the A.C. Range and Bearing Clock Mark II': although it actually described in detail a design with only one of the new drives, for the generation of ranges. To set its rate, the roller carriage was coupled directly to the rate generating mechanism (Plate 21). The latter changed considerably as the design developed (XII-9), but from the start it embodied the essential Dumaresq principles: the vector addition of enemy-speed and own-speed-reversed to obtain virtual-speeds along and across the line of bearing. However, to simplify mechanical transfer, the line of bearing was fixed, with rotating slots or links to represent both courses. In the Mark II, target bearings were set by hand, even when courses were steady. If own course changed, it was also necessary to throw a lever, which held the enemy inclination fixed until the turn was completed.[96] This was the same approximation used in the Dumaresq Mark VI. Pollen usually insisted that the effect of change of bearing on rate and range must not be neglected:[97] yet here it was largely dismissed.

> This [approximation] neglects the change of bearing due to alteration of position during turn but at long ranges the error introduced is very small.

Submission and Observations', all in T.173/91 Part XI. These statements should be treated with reserve, since the Admiralty's evidence to the RCAI was intended to establish that that the Service system owed nothing to Pollen: but they cannot be ignored.

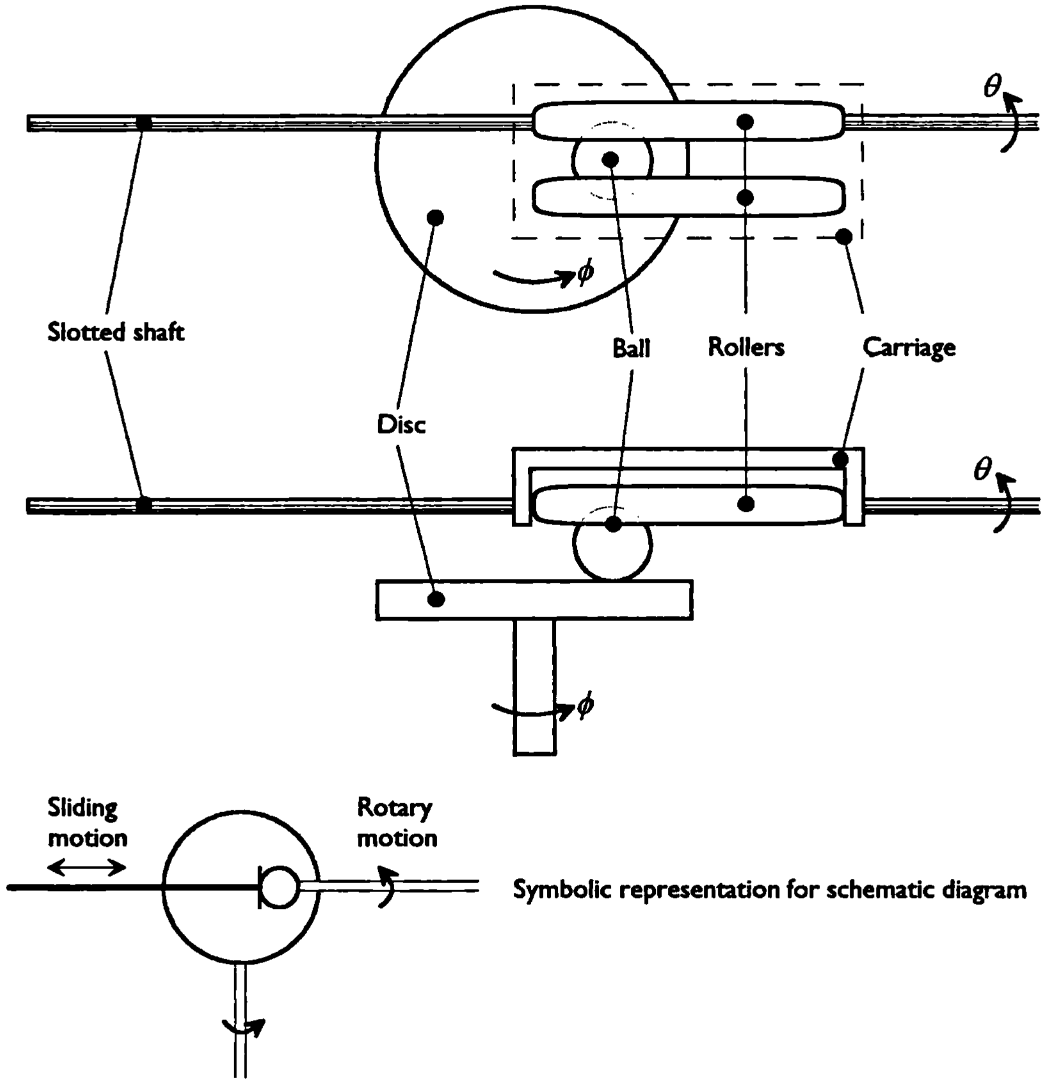
[93] Admiralty, Gunnery Branch, *Handbook of Naval Range-Finders and Mountings 1921*, ADM 186/253 (reference courtesy Mr. John Roberts). The *Iron Duke* class were the exception.

[94] Admiralty, Technical Historical Section, *The Technical History and Index...*, 'Fire Control in H.M.Ships', TH23, p.20, AL. See also A E Fanning, *Steady as She Goes* (London, 1986) p.195.

[95] Patent 17,441/1912 applied for with complete specification 4 April.

[96] 'The A.C. Range and Bearing Clock Mark II' accompanying a letter from I E Brown, Secretary, Argo Company to the Secretary of the Admiralty, 15 May 1911 in T.173/91 Part III.

[97] *PP*, 'Apology for A.C.' (1907) pp.148,151 and 153.



The rotation rate of the output slotted shaft is proportional to the distance of the ball from the centre of the disc.
The rate is changed by moving the carriage. The rollers then roll the ball along the disc diameter while it continues to rotate due to the driving action of the disc. Even when the rate is changing, the ball remains in rolling contact with disc and rollers, without slipping.

FIG. 4.1: ARGO VARIABLE SPEED DRIVE

The Mark II proposal also described a mechanism for calculating the change-of-range in time-of-flight: and the spiral range scale which was to become a feature of all later Argo clocks. It also declared that:

> By the addition of a simple linkage and another variable speed drive, "Bearings" can be operated automatically....the Mark II Clock will [then] do all that the A.C. Mark I Clock will do...but will also indicate deflection due to speeds.

but it admitted that:

> ...subsidiary portions such as "transmitter drive", "spotting corrections", "motor speed control" etc. are but vaguely indicated, as the problems introduced by them are the ordinary problems incidental and usual in Engineering design.[98]

The importance of the new design was recognised immediately in the Admiralty. On 22 May, Pollen wrote to Isherwood:

> While it is fresh in my mind, I had a talk with Henley today and explained to him the proposed additions and alterations to the Clock. He suggested we should send a sketch...showing a clock with automatic bearing generating and that could be set either by speed and course or by rates of change.[99]

Henley himself wrote privately to Dreyer on 24 July: 'I think their [Argo's] new design is going to be a great improvement on the old and hope to get one for trial'.[100]

Pollen and Isherwood applied for a patent on 4 September but the provisional specification added little to the earlier proposal.[101] Nevertheless:

> On 11th October 1911...Henley inspected the working drawings of the Argo Clock at York and the Clock itself which was then under construction.[102]

The finished instrument (Plate 20) was ready for inspection by the end of January 1912,[103] while a complete patent specification was left on 4 April.[104] Isherwood had introduced two more variable speed drives to integrate speed-across and to divide by the range to get a change-of-bearing, which was then applied to the dumaresq-mechanism (Fig. 4.2 and Plate 22 and 23). By this 'cross-connection' of the integrators and the Dumaresq, the clock could, while courses were steady, solve 'the ever-changing triangle of velocities'

[98] 'A.C. Clock Mark II' (*op. cit.*).
[99] Pollen to Isherwood, 22 May 1911 in T.173/91 Part III.
[100] Henley to Dreyer, 1911 (*op. cit.*).
[101] Patent 19,627/1911, Provisional Specification in T.173/91 Part III. Because this patent was not reassigned to Pollen, it was never printed by the British Patent Office.
[102] 'Statement of the Claimant's Case' in T.173/91 Part XI.
[103] Argo to the Secretary of the Admiralty, 26 January 1912 in T.173/91 Part II.
[104] Patent 19,627/1911, Complete Specification in T.173/91 Part III. The Argo patent later taken out in the United States (1,162,510, filed 5 September 1913) contained essentially identical drawings and text (except for the final claims).

continuously and automatically.[105] However, if own-course altered, target bearings had to be set by hand, while the control lever (labelled STEADY-TURNING) held the inclination constant (XII-10). Despite its mathematical elegance, the new clock was neither helm-free nor exact in a turn.

The range dial now had two hands, for both rangefinder and gun ranges, the difference between them being set by means of a spotting-correction pointer and scales.[106] The clock was also supposed to drive a follow-the-pointer transmitter to send gun-ranges to the sights. However, the patented design was flawed, most seriously in that the transmitter shaft did not register the spotting corrections (XII-10); perhaps, after the earlier airy dismissal of these issues, they had been given insufficient attention.

Since the five Argo clocks ordered later in 1912 were designated Mark IV, it may reasonably be supposed that the clock eventually tried in *Orion* was the only Mark III. Unfortunately, it is not clear how far its actual construction advanced beyond the patented design. The spotting pointer and scales appear to have been added later, while, since the clock was still in the factory in the third week in July, there was certainly time for further alterations. The trials were delayed partly by *Orion's* participation (with *Thunderer*) in the director trials[107] but also 'by alterations necessitated to the clock as a result of suggestions by various Naval Officers'; also, even after the trials, the arrangements for transmitting ranges to the sights had 'not yet been settled'[108] and, as finally implemented for the Mark IV, they were of some complexity. Whatever its exact build state, the experiments and trials were successful (XII-11).

> The Clock [was] thoroughly tested in..."Orion"...and has worked well....On the whole...it solves in an efficient and reliable manner the problem which it undertakes.[109]

In the Argo Clock Mark IV (Plate 24 and XII-12), the arrangements for applying spotting corrections had been elaborated, while a pointer showing enemy inclination had been added. Internally, the mechanism controlled by the STEADY-TURNING lever had been redesigned so that the inclination was maintained exactly through a turn: provided

[105] Boys to Pollen (1912) (*op. cit.*).
[106] The change-of-range in time-of-flight was now set as a spotting correction, the special calculating mechanism having been dropped.
[107] *IDNS*, pp.222 and 229. The spotting pointer and scales were evidently last-minute additions to the patent, since they are not mentioned in the text.
[108] *Technical Comparison* (1913) pp.11 and 33.
[109] *ibid.* p.34. For the conditions of the tests, in which any inclination errors would not have been apparent (XII-11), see Rear-Admiral Craig Waller before the RCAI, T.173/547, Part 12, p.13: 'Full Charge Run' and '3/4 Charge Run' in the Craig Waller Papers and *IDNS*, pp.231-2.

that, as before, the target bearing was set correctly by hand throughout. The most obvious external change was the addition of the side extension carrying a follow-the-pointer range receiver with two hands (Plate 25). The associated transmitters and gearboxes enabled the clock to transmit ranges without operator intervention, but only until a range or spotting correction was put on the clock. This caused the two receiver hands to diverge, and the correction was only transmitted when an operator worked a handle to bring the hands back into alignment.[110] Thus these clocks were still neither helm-free nor fully automatic in transmitting ranges to the latest turret sights.

A C COMPLETED

Design work on an entirely new Argo true-course plotter did not restart until the turn of 1911-12. Detailed drawings were ready by the following September but the prototype plotter itself was not completed until April 1913, after significant amendments to the design.[111] This Mark IV plotter (Plate 26) charted enemy course with a fixed pencil, but, while the design was theoretically correct, there are several reasons for doubting its accuracy and utility. Firstly, bearings were transmitted in rather coarse steps of ¼°: and it used the same magnetic-clutch receiver motors which were troublesome in the *Orion* rate plotter. Secondly, the Phillpotts committee concluded:

> The Gyro compass and Forbes log [are] not...even yet...sufficiently reliable...to enable own ship's motion to be accurately dealt with. Hence a confused plot results.[112]

Thirdly, the chart was both rotated and advanced by the action of long trains of differential gears; these lacked any apparent provisions to minimise the backlash which, especially at long range, would have resulted in significant errors in the position of the chart under the enemy pencil. Fourthly, the plotter was always connected to a single Argo rangefinder mounting. Since the power-cut had not worked, the transmitted ranges fluctuated between cuts, which must have scattered the majority of minute marks intended for determining enemy speed.[113] These would have confused the plot while providing little help in speed measurement (XII-13). Argo proposed a multi-pointer range receiver (Plate

[110] Gunnery Branch, *The Argo Range and Bearing Clock Mark IV*, 10 January 1914, AL.
[111] *IDNS*, pp.215, 225 and 230. The provisional specification for patent 23,349 applied for 12 October 1912 was, unusually, accompanied by detailed drawings. The complete specification left on 11 April 1913 had an additional Fig.4 showing two extra differentials.
[112] Phillpotts Committee, 'Report' (*op. cit.*) pp.2 and 6.
[113] The description and illustrations of the Mark IV plotter in *Technical Comparison* (1913) pp.25 and 28-30 are similar to the patent. See p.36 for obtaining speeds from pairs of plotted points.

27) for meaning the ranges from several rangefinders; it might, perhaps, have been workable with continuous ranges from a power-cut, but not otherwise, and it never progressed beyond a cardboard model.[114] Finally, there was no convenient means of measuring the mean range from the plot, while enemy range, course and speed could only be transferred to the clock manually.[115]

The Mark IV plotter was never tried by the Royal Navy, but Pollen claimed complete success for the whole Argo system in trials by the Russian Navy in June 1914. Although the firm then received an order for five complete installations, in October they shipped to Russia only three rangefinders and mountings and two Mark V clocks with gyroscopes.[116] The cancellation of the plotters does nothing to dispel the doubts about the Mark IV as a practicable helm-free plotter.

The final Argo clock, the Mark V of 1913, was at last truly helm-free. A compass ring was placed around the main Dumaresq dial (Plate 29). By means of a connection to a relay motor controlled by a gyro-compass receiver, the internal links representing own and enemy courses were maintained automatically at the correct angles.[117] The mechanism for generating change of bearing was also completely redesigned.[118] The changes appear to have been made to avoid the risk of slippage in the second variable speed drive when it was dividing by exceptionally low ranges (XII-14). However, there is no evidence for such slippage in the Mark IV clocks. The Phillpotts Committee had nothing but praise for the clock as a mechanism. Their main criticism was of its lack of integration with the plotter.

> There is no record on paper of what the clock is doing in comparison with the information given by the plot.[119]

[114] The averaging receiver was patented by Pollen and Lieutenant Gerard Riley (see *IDNS*, pp.215-6) as 25,768/1912 applied for 9 November. The cardboard model was seen in 1918 by the Phillpotts Committee, who thought it 'very doubtful if this method could cope' with wartime conditions: 'Report', pp.1 and 3

[115] *Technical Comparison* (1913) pp.35 and 41. Phillpotts Committee, 'Report', p.1. Boys to Pollen (1912).

[116] *IDNS*, pp.247-8, 282 and 295-6. For the Russian order, see A H Pollen, 'Memorandum on Fire Control', 1916 in T.173/91 Part II

[117] Patent 11,009/1913, applied for 9 May, complete specification 8 December; also U S Patent 1,162,511, filed 14 April 1914.

[118] Patent 16,373/1913 applied for 16 July, complete specification 16 January 1914: also US Patent 1,232,968, filed 11 July 1914. In August 1914, the Admiralty believed that this patent 'describes the mechanism of the latest type of Argo clock...already...on the open market': DNO's minute of 18 August 1914 quoted in Admiralty to C.-in-C. Home Fleets, March 1916 in 'Fire Control Apparatus: Various Patents', ADM 1/8464/181

[119] Phillpotts Committee, 'Report', p.6.

By 1913, the three essential components of the A C system had reached their final forms. Yet, in the middle of that year, Argo were removed form the list of Admiralty suppliers. It is now necessary to trace the commercial relationship between Pollen and the Admiralty from his first proposal to the final rupture.

COMMERCIAL

Even Pollen's earliest approach to the Admiralty went straight to the top. In putting forward his two-position rangefinder in 1901, he wrote directly to the First Naval Lord, Lord Walter Kerr, a family friend and fellow Roman-Catholic.[120] Presumably following Kerr's advice, Pollen then approached Lord Selborne, the First Lord, but insisted that:

> Before submitting...drawings...we shall have to ask that a binding pledge of secrecy shall be given and an undertaking in no way to imitate or use the entirely novel mechanical and mathematical principles incorporated in the machine.[121]

Since both Watkin and Fiske two-position rangefinders had been found wanting during the *Arethusa* trials,[122] Pollen's claims were probably treated sceptically and, on 7 February, he was informed that his invention 'does not seem to the Admiralty to offer them advantages sufficiently good to warrant their buying the secret'.[123]

On 9 May 1904, Sir Joseph Lawrence MP, Pollen's father-in-law and Chairman of Linotype, wrote to Selborne announcing that the calculating machine had been perfected.

> People who have heard...of the invention have made approaches with a view to acquiring the Patents, possibly for foreign navies.

while, as in 1901, the accompanying Memorandum emphasised that knowledge of enemy course and speed

> ...would enormously simplify all cruiser tactics....The secondary use which this device could be put to would be as a rangefinder for guns.

By 27 May, after Pollen had seen the DNO, Captain H D Barry, Lawrence again wrote to the First Lord, urging:

> Is it not worth some experimenting with, or must it be dealt with on purely commercial lines, which would necessarily deprive the Admiralty of any opportunity of getting a monopoly of the system when it is evolved.

[120] Information on Kerr courtesy Professor Andrew Lambert.
[121] Pollen to Selborne, 4 February 1901 in T.173/91 Part VII.
[122] Peter Padfield, *Guns at Sea* (London, 1974) p.221.
[123] *IDNS*, p. 79.

However, Barry considered that Pollen's instrument 'is in no sense a rangefinder' for shipboard use.

> I explained the whole case clearly to Mr. Pollen...& said it was not the instrument that the Admiralty wanted. He replied that he wanted - "the Admiralty to take what they didn't want".
>
> ....
>
> I may say I know the Pollen family personally and they are all pushing and persistent.[124]

Barry's opinion was confirmed when Pollen succeeded in going over his head to meet with Lord Walter Kerr and Admiral May, the Controller. Because of problems with procuring more accurate one-observer rangefinders, May was prepared to consider a 'double-observer instruments with good communications at all events for trial', but Pollen was told that any experimental installation must wait on the completion of the other instruments.[125] In November, Pollen claimed in two letters to the Admiralty that 'it may be confidently said that [the system] has passed the experimental stage' and the 'system has now been completed'.[126] Barry preferred to leave a decision to his successor, Captain John Jellicoe,[127] DNO from February 1905. On 3 April, Captain Edward Harding RMA (one of the DNO's assistants) wrote a highly favourable report on preliminary experiments in *Narcissus* with the observation units;[128] a month later, Pollen was informed that his terms had been accepted for the supply by 1 October at latest, or earlier if possible, of two observation units with bearing transmitters, the machines for computing range from the bearings, and a charting table. The 'Rate of Change machine was:

> To be put in hand as soon as the final designs are decided upon and delivered as part of the order at probably a later date....[129]

Pollen was to receive £1500 for manufacturing costs, £2000 for expenses incurred in the preceding five years plus £1000 for his services during the trials.[130] He subsequently received all these sums, though, instead of the clock, he deftly substituted a 'tactical

[124] Lawrence to Selborne with 'Memorandum', both 9 May 1904: Lawrence to Selborne, 27 May and minute by H D Barry, 31 May 1904 in 'The Pollen Rangefinder' in ADM 1/7733.
[125] Pollen to V W Baddeley, 5 July 1904 in ' Pollen Rangefinder' (*op. cit.*). Minute by W H May 13 July 1904 in 'Report of Committees on Control of Fire' in ADM 1/7758.
[126] Pollen to First Lord, 14 November and Pollen to Skinner received 24 November 1904 in 'Pollen Rangefinder'.
[127] Harding before RCAI, T.173/547 Part 3, p.31.
[128] *IDNS*, p.84.
[129] Secretary of the Admiralty to Pollen, 3 May 1905 in T.173/91 Part VII.
[130] *PP*, Pollen to Tweedmouth, 27 August 1906, p.217.

change of range machine'[131] which was 'not a machine for shooting'[132] but a tactical aid for predicting future relative positions (XIV-1).

JUPITER TO *ARIADNE*

Shortly after the *Jupiter* trials, on 13 February 1906, Pollen wrote to Jellicoe proposing the use of the 'best one observer rangefinder that the market can supply';[133] the letter was also copied to the First Lord, now Lord Tweedmouth. Despite the inevitably unfavourable report on the trials, Pollen was encouraged to submit his new ideas and, by 18 June, had completed a proposal entitled the 'One Observer System of Charting' . In late June, at a conference of experts, Harding (supported by Percy Scott) argued successfully in favour of secrecy; afterwards, Harding wrote describing the discussions, so he was now serving Pollen inside the Admiralty as both advocate and informant. After the conference, at the insistence of the Controller, Rear-Admiral Sir Henry Jackson, Jellicoe raised the possibility of plotting by non-automatic methods but Pollen was able to persuade him that such an attempt would be futile.[134]

On 9 August, following a decision of the Board,[135] negotiations began on a new agreement to purchase equipment for trial and, in the event of success, for supply in quantity (XIV-2). Pollen initially demanded £8,000 for the trial system, although this figure included £3,600 towards his earlier development costs; the Admiralty side was reluctant 'to make good his losses on a trial that was unsuccessful'. He was also told that his hope for a guarantee to equip 12 ships a year for 15 years, worth, it was estimated, some £300,000, was out of the question. This sum was intended as a consideration for giving up his foreign markets, but, when it was pointed out to Pollen that 'inventors usually have to perfect their inventions at their own expense', he declared that he would be seeking much more for a completed system and that 'he had had offers from a Foreign Government and from large firms to take it up'. The Admiralty representatives then expressed their concern that Pollen:

[131] Pollen to the Secretary of the Admiralty, 18 June 1906 in T.173/91 Part II.
[132] Pollen's counsel before RCAI, T.193/547 Part 7, p.27.
[133] Pollen to Jellicoe, 13 February 1906 in T.173/91, Part I.
[134] *IDNS*, pp.90-1. *PP*, 'Note on the possibility of demonstrating the principle of Aim Correction without... instruments designed for the purpose...', pp.101-4. The copy of this paper in T.173/91 Part VII is dated 21 July 1906.
[135] *Admiralty Board Minutes, 7 August 1906* in ADM 167/40.

> ...could not fail to acquire further knowledge of range-finding in general and of British Naval methods in particular, in addition to that which he already owes to us, and that it might be serious to us if we then decided to let him go abroad with that knowledge....

which explains why they had insisted that Pollen was:

> ...to attend preliminary trials to see any necessary adjustments carried out...and to demonstrate the utility of his invention...but not to be present at the final trials.[136]

On the following day, Pollen informed the Admiralty that 'The smallest sum which would enable me to carry on is £6,500'. He also proposed conditions which, after the *Ariadne* trials, were to prove much more to the Admiralty's advantage than his own.

> The Admiralty to decide, after two months working of the instruments... whether or not they wish to acquire a monopoly of my system.[137]

On 21 August, the Admiralty agreed to £6,500 for the trial instruments, but, at some point, Pollen was also paid an additional £802/10/- towards 'expenses which he had not anticipated' for the earlier trials.

In their letter of 21 August, the Admiralty refused to entertain more than £90,000 for monopoly; by this time, a clock no longer figured in the negotiations, the agreement relating only to the supply of the rangefinder mounting and plotting table.[138] On 27 August, Pollen again wrote directly to the First Lord, still asking for a total payment of £255,000, on the grounds that:

> ...what I have to sell is not instruments but a system, the embodiment of certain laws of gunnery which I was the first to codify....The monopoly of instruments is only incidental.[139]

While these exchanges had been taking place, Captain Harding had been preparing a 'Memorandum upon the Professional and Financial Value of the A.C. System'. This he submitted to Jellicoe on 4 September, while informing Pollen that:

> I have got out a regular snorter for the D.N.O., if it doesn't convince him nothing will.[140]

As might be expected, his arguments are often similar to Pollen's.[141]

[136] *IDNS*, p.92. 'Pollen Aim Correcting Apparatus. Notes of a meeting held at the Admiralty in the Board Room on 9th August 1906', T.173/91 Part II.
[137] Pollen to the Secretary of the Admiralty, 10 August 1906 in T.173/91 Part VII.
[138] Secretary of the Admiralty to Pollen, 21 August 1906 in T.173/91 Part II. *Pollen Aim Correction System. General Grounds of Admiralty Policy and Historical Record of Business Negotiations*, Admiralty, February 1913, p.7, P.1024, AL. Alan Rae Smith of Deloitte, Plender, Griffiths & Co., 'The Argo Company Limited', 9 October 1923 in T.173/91 Part I.
[139] *PP*, Pollen to Tweedmouth, 27 August and Tweedmouth to Pollen, 3 September 1906, pp.218 and 220-1.
[140] *IDNS*, p.95.
[141] Pollen himself was handed the manuscript of Harding's report and also acquired the typewritten copy

> Throughout the negotiations he [Pollen] has laid more stress on the principles involved...on the idea, that is to say, than on the details of the mechanism.[142]

His technical assessment relied on the false assumption that, by course plotting, the 'errors of individual readings of the Range Finder [may be] eliminated': and, therefore, that geometric range could be found without observation of fire and, consequently, concentration would be more effective. Concerning the originality of the system, Harding affirmed that 'the necessity for some form of gyroscopic control is probably totally unrecognised' elsewhere: but he acknowledged that:

> ...the solution of plotting only occurred incidentally to Mr. Pollen and it was not immediately that he recognised its technical application and importance.

and that:

> Probably every Coast Artillery Control system in the World employs some form of chart, but it may be said with safety that not one of them uses it exactly in this way.

Notwithstanding these reservations about the originality of Pollen's plotter (XIV-3), Harding gave his full support to the inventor's negotiating stance.

> IN CONCLUSION the system will be of immense national value as a monopoly.... the sum thus spent must be looked upon as an insurance against the possible acquisition of the invention by other powers or as money spent on research, and not as relieving the inventor of financial risk.[143]

Despite Harding's uncritical assessment of the *Jupiter* bearing instruments and his close association with Pollen since before the trials,[144] his superiors appear to have been persuaded by his recommendations. Sumida makes a convincing case that his memorandum (or a précis by Jellicoe) was instrumental in persuading Fisher that a monopoly of Pollen's gear must be obtained.[145] Thus, on 21 September, the Admiralty agreed to Pollen's two-month limit for a decision: and, for exclusive rights, offered £100,000 (on top of manufacturing cost plus 25% profit) for the first 40 installations.[146] By 29 October, provisional agreement on contractual terms enabled the Admiralty to pay the £6,500 for the trial instruments.[147] Furthermore, the report of the Naval Estimates

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with Jellicoe's marginal notes: Pollen's counsel before RCAI, T.173/547 Part 13, pp.69 and 89.

[142] Harding's description of the 'present system' - which did not mention rate plotting (*pace IDNS*, pp.91 and 96) - and his evidence before the RCAI (T.173/547, Part 14, pp.9, 11-2 and 34) are quoted in XIV-3.

[143] Harding, 'Memorandum upon the Professional and Financial Value of the A.C. System' with Harding to Jellicoe, 4 September 1906 in T.173/91 Part VII.

[144] Harding acknowledged to the RCAI that from the autumn of 1904 onwards he saw a good deal of Pollen (T.173/547 Part 14, p.26) and that 'I was very enthusiastic...possibly over enthusiastic' (T.173/547 Part 3, p.31).

[145] *IDNS*, pp.95 and 98-9.

[146] Secretary of the Admiralty to Pollen, 21st September 1906 in T.173/91 Parts II and VII.

[147] *IDNS*, pp.115-6.

Committee of 26 November included in the 1907-08 estimates a provision of £62,500 for 'Pollen's aim-correcting apparatus', despite the adverse effect on attempts to reduce expenditure.[148]

With the immediate urgency removed, the Admiralty did not send Pollen a draft contract until 11 March 1907, but this only initiated another protracted round of negotiations. At one point, Pollen seems to have been accused of sharp practice, while, on 31 July, he declared that 'the whole purpose...of the Admiralty has been...to leave us in the position of an expropriated patentee'.[149] Thus the temper of the discussions had deteriorated even while Jellicoe was still at the Admiralty. Pollen later admitted to Bacon:

> Your predecessor took the line (which undoubtedly was right) that, until the Service had made up its mind about the A.C. gear, I had to be regarded as a person who might at any moment be making his knowledge and experience of gunnery available to the world.[150]

Although the formal contract was still unsigned, *Ariadne* had been nominated as the trial ship[151] and, by 20 November, the instruments had been installed aboard and were inspected by Admiral of the Fleet Sir Arthur Wilson. Initially, his relations with Pollen were cordial.[152] Furthermore, in November the Admiralty were still anticipating a favourable outcome to the trials, since the Navy Estimates Committee assumed that, for the year 1908-9:

> 50,000l. [£50,000] has to be re-provided...to meet the liability in respect of the Pollen Aim Corrector which will not mature during the current year.[153]

However, on 8 December, Wilson asked Pollen for 'a written statement showing exactly what are the advantages you claim for your system...'. Pollen responded with a copy of 'An Apology for the A.C. System' but this only helped Wilson to appreciate both that the system was incomplete and that the Admiralty's rights were limited to only a part of it. Shortly afterwards, at the end of a second inspection, Wilson turned on Pollen demanding:

[148] Navy Estimates Committee, *Report upon Navy Estimates for 1907-8*, 27 November 1906, FISR 8/10, CC. The sum allowed suggests that the Admiralty assumed Pollen would be ready to supply production models in 1907-8: but that they intended to pay for monopoly in instalments, as stipulated by the final contract.
[149] *IDNS*, pp.116-9.
[150] *PP*, Pollen to Bacon, 27 February 1908, p.174.
[151] Pollen to Bacon, 3 August 1907 in T.173/91 Part VII.
[152] *IDNS*, p.124.
[153] Navy Estimates Committee, *Report upon Navy Estimates for 1908-9*, p.4, FISR 8/11. See also *Navy Estimates 1908-09*, 18 December 1907, CAB 37/90/112, PRO. £50,000 was to be paid within one month of Pollen being notified of a decision, then two payments of £25,000 after 12 and 24 months: 'Indenture of Agreement between the Commissioners of the Admiralty and Mr. A. H. Pollen, 18 February 1908' in T.173/91 Parts II and VII.

> You will have to explain to me sometime or other why on earth the Admiralty should pay you £100,000 more than to Barr and Stroud or any other maker of Fire Control instruments that have got to be used for your system.[154]

There can be no doubt that, by the turn of the year, Wilson had concluded that Pollen's exceptional treatment was unjustified and that the trials must demonstrate that the inexpensive manual system in *Vengeance* could produce satisfactory results. By the luck of the draw, the conditions on 15 January 1908 were so easy that neither ship had any difficulty in keeping the range: but the results allowed Wilson peremptorily to call a halt and order *Ariadne*'s return to port. It is hardly surprising that, ever afterwards, Pollen was convinced that he had been cheated of the opportunity to demonstrate the superiority of his gear in more demanding circumstances.

ARIADNE TO *NATAL*

In his comments on the trials, Pollen assumed (and Wilson does not seem to have disagreed in his own report of 31 January 1908) that the 'complete success' conditions had been met.

> The sum the Lords Commissioners have agreed to pay for monopoly...can now neither be increased by my system being shown to be better than has already been proved, nor diminished, as partial failure might have caused it to be.... If I had such attractive offers from foreign navies when nothing was proved, is it likely that they will not materialise when everything is established.[155]

On 25 February, Pollen wrote to Bacon about an idea for a mechanism which could indicate enemy speed and course if set only with two positions and the time between them. Bacon replied:

> The mechanism...must be most ingenious but how far mechanisms should supersede the human brain involves serious practical consideration.

which must have added to Pollen's concerns about the attitude of the DNO, who refused to meet him.[156] Pollen wrote back, arguing for a complete automatic system and declaring, with his usual assumption that a concept was as good as a finished design:

> My change of range clock was designed before we left the *Jupiter*, and the sight setting mechanism, to be run straight from the range clock, very shortly after.

[154] *IDNS*, pp.124-6. See also *PP*, Pollen to Wilson, 17 December 1907, p.168.
[155] *PP*, Pollen to Wilson, 24 January 1908, pp.159-160 and 165. *IDNS*, p.131.
[156] Pollen to Bacon, 25 February and Bacon to Pollen, 26 February 1908 in T.173/91 Part VII. *IDNS*, p.132.

Pollen also printed extracts from his letter for circulation to senior members of the Admiralty hierarchy[157] but Bacon was not intimidated into changing his views.[158]

The formal contract with Argo had not been signed until 18 February, a month after the trial had been terminated. It stipulated that:

> If complete success can be obtained at the trials *and* if the Commissioners thereupon decide to acquire the sole and exclusive rights to use the Pollen Aim Correction System...*and* shall give to the Inventor within one calendar month from the...completion of the...trials notice in writing...the Inventor shall forthwith grant [said] rights [present author's italics].[159]

Thus Pollen could still hope for a decision in his favour: yet the Admiralty could reject exclusive rights *even though* complete success had been attained. In fact, other political pressures had already made this the most likely outcome. On 26 November 1907, the Cabinet had refused to accept the proposed Navy Estimates, which represented an increase over the previous year of £2,150,000. After spirited discussions, by the beginning of February the increase had been reduced to only £900,000;[160] thus Pollen's award must have been a tempting candidate for the inevitable cuts.

Even so, no decision had been taken by 2 March, when Pollen wrote to Tweedmouth asking to see the parts of Wilson's report dealing with 'matters of fact' and directly criticising the Admiral.

> On certain mechanical questions, he [Wilson] seemed not to have given himself time to understand either the principles or actual working of the instruments.

Pollen also risked causing further serious offence by comparing his present situation with 'the straightforward and honourable way in which their Lordships treated me on the occasion of the *Jupiter* trials'. Nonetheless, on 6 March the Admiralty offered further trials. In his reply of 9 March, Pollen only 'noted' the proposal, regretted that other business would prevent his continuous attendance, and also questioned why the Admiralty assumed that the contract of 18 February made provision for additional trials.[161] However, he undertook to make Isherwood and his engineers available 'at a moment's notice'; he was therefore dumbfounded to receive the letter of 10 March in which the Admiralty purported to infer that:

[157] Editor's introduction, *PP*, pp.172-5.
[158] For Bacon's reply and the extent of his scepticism regarding mechanised gunnery, see XIV-4.
[159] 'Indenture of Agreement 18 February 1908' (*op. cit.*).
[160] Arthur J. Marder, *From the Dreadnought to Scapa Flow, Volume I* (London, 1961) p.137-8. R F Mackay, *Fisher of Kilverstone* (Oxford, 1973) pp.386-392.
[161] The agreement only provided for new trials if complete success had not been achieved initially but new designs were submitted subsequently.

> By your letter of the 9th March, you do not appear to wish these further trials to take place. In the absence of such further trials, the Agreement between yourself and the Admiralty will expire on the 14th instant.

He was informed that:

> My Lords have...decided not to exercise the option...of acquiring the sole rights of the 'Aim Corrector System'.
> ...as from your letter to Sir A. Wilson of the 24th January they understand you wish to enter into negotiations with certain Foreign Powers, they would be glad to know if you are desirous of re-purchasing the [*Ariadne*] instruments....[162]

At just this moment, the First Lord's position had been fatally weakened after, on 9 March in the House of Lords, he had failed to defend his correspondence with the Kaiser about the British Navy Estimates.[163] Tweedmouth, not unnaturally, refused to see Pollen on the 10th; by then, the First Lord was in no position to force yet another change in policy. Further, if the new trials were indeed outside the Agreement, the expiry date was now very close (it was ironic that, in 1906, it was Pollen who insisted on a two-month deadline). And, Pollen's imputations against the present Board and particularly his attack on Wilson probably undermined any remaining support, since he found it necessary to declare:

> I am most anxious that no member of the Board should think that I wish in any way to reflect on Sir Arthur Wilson.[164]

While Pollen's £100,000 was lost for good, the Board were agreed that he should receive an award to cover his expenses and contribution to the development of fire control, though they were still divided on the question of secrecy.[165] After new negotiations, by 18 June it had been agreed that secrecy would be maintained for a further 18 months, that the *Ariadne* instruments (including the rangefinder) would be returned, and that Pollen would receive a payment of £11,500.[166] At least at first, he took a remarkably sanguine view of this outcome.

> In binding myself...not to approach any foreign power for a year, I am not in the slightest degree hurting the commercial development of the thing, and...I am getting the working capital necessary to carry on with it without the necessity of making it public.

[162] Pollen printed the correspondence from 2 to 10 March in his 1909 pamphlet: *PP*, 'Notes on *Ariadne* Trials' (1909) pp.225-230. Note that, at some point, the deadline for a decision had been extended from one to two months after the end of the trials.
[163] *FDSF I* (*op. cit.*) pp.140-2.
[164] *PP*, Pollen to individual members of the Board of Admiralty, 25 March 1908, p.231.
[165] *Admiralty Board Minutes, 31 March 1908*, ADM 167/42.
[166] The correspondence leading to the new agreement is in T.173/91 Part VII.

> This is virtually understood, I think, at the Admiralty...by Jackie & Co. that the thing will be reopened.[167]

With funding secured, Pollen and Isherwood were free to tackle the defects in the *Ariadne* gear and to begin work on the clock. Pollen also found time to write 'Reflections on an Error of the Day'. This pamphlet began with a critique of time-and-range plotting, especially when used in conjunction with a second 'curve of rate'. Nevertheless, Pollen still claimed to have been the first to think of range-rate plotting, though we 'did not proceed...for the reason that it seemed to us both unscientific and impracticable'.[168] However, no mention was made of plotting bearings against time

On 5 January 1909, Pollen announced the formation of the Argo Company, although, in fact, the company had been registered on 31 December 1907, with Pollen as the only major shareholder.[169] He declared:

> Unlike the devices tried in the Jupiter and Ariadne, which were experimental sections of the system, the gear we are now building will be in all respects fitted to its purpose as integral parts of a fighting ship's equipment...
> ...the A.C. system owed its complete development largely to the £22,000 of public money voted to Mr. Pollen...and the exceptional opportunities for study and investigation that the experiments in H.M.S. Jupiter and H.M.S. Ariadne afforded.[170]

Pollen had submitted his Argo prospectus just as the Navy Scare of early 1909 was coming to the boil.[171] Despite this not inconsiderable distraction, on 12 February his proposal for further trials was discussed by the Admiralty Board, on which Jackson had been replaced as Controller by Jellicoe.

> A circular letter to the Fleet to be prepared informing the Service that Mr. Pollen having formed a commercial company was now in the position of an ordinary manufacturer.[172]

At a meeting with Bacon on 15 February:

> The DNO informed me [Pollen] that it was desired to make further investigation into the value of the Gyroscopic Control of the Range finder...I am not to quote for the Automatic Charting devices...it had been decided not to re-open the question of monopoly or a possible extension of the period of secrecy'.[173]

However, having obtained Pollen's acceptance that the agreement of February 1908 had expired, on 4 March the Board overruled the DNO.

[167] *IDNS*, pp.137-8.
[168] *PP*, 'Reflections on the Error of the Day', September 1908, pp. 180-1 and 183.
[169] Rae Smith, 'Argo' (*op. cit.*).
[170] Pollen to the Secretary of the Admiralty, 5 January 1909 in T.173/91 Part II.
[171] *FDSF I*, pp. 159-71.
[172] *Admiralty Board Minutes, 12 February 1909*, ADM 167/43.
[173] Pollen to the Secretary of the Admiralty, 15 February 1909 in T.173/91 Part VII.

> The First Sea Lord [Fisher] to see the Director of Naval Ordnance who is to arrange for the purchase of a complete set of apparatus.[174]

However, Pollen had heard nothing further by 22 March. By this time, the demands that 'We want eight, and we won't wait' were reaching their crescendo and a vote of censure on the Government's dreadnought programme was to be held on 29 March. Pollen seized his opportunity for a piece of blatant political arm-twisting, writing to the First Lord, Reginald McKenna, of his fears that:

> ...those who succeeded in turning the Ariadne trials into a mockery last year may do their best to prevent my getting a prompt and fair trial now.
> ....
> ...for the last three days, I have been doing my utmost to prevent this matter being brought up in the Unionist Press and the House of Commons....the Front Bench Unionists, who were formally members of the Board, are perfectly familiar with...my inventions....it is believed a very strong polemical value would attach to bringing the matter out in the forthcoming vote of censure.
> ...I hope...that I have prevented this matter being publicly discussed. But naturally I should like to hear from you whether this assurance I have given has any foundation.

At a brief meeting with Jellicoe on 24 March, Pollen was given to understand that he might be asked to tender for a trial of his complete Battle System[175] and Argo received a formal request to tender for a complete trial on 2 April.[176]

Fisher probably assented only reluctantly to this invitation. Pollen's relations with Beresford and Custance were cordial and of long standing, while, in 1908, Beresford had unsuccessfully sought permission for Pollen to attend a Battle Practice and had declared that 'Pollen's manual time-course plotting scheme was superior to the methods recommended by the Ordnance Department'.[177] The letter to Tweedmouth of 22 March then revealed that Pollen was in touch with the Conservative opposition, though its implied threats evidently could not be ignored. Fisher's antipathy was quickly reinforced when, also on 2 April, the First Sea Lord was criticised both in an anonymous *Times* article: and then in a speech by Sir George Armstrong.[178] Fisher believed Pollen was involved in both attacks.

[174] *Admiralty Board Minutes, 18 February* and *4 March 1909*, ADM 167/43. *IDNS*, p.164.
[175] Pollen to McKenna, 22 and 25 March 1909 in MCKN 3/14, CC. He may have received more definite confirmation from McKenna in a letter of the 23 March: Pollen to McKenna, 20 April 1909 in T.173/91 Part VII
[176] *IDNS*, p.164.
[177] *ibid.* pp.168-9.
[178] *FDSF I*, p.190. Mackay, *Fisher* (*op. cit.*) p.412.

> I have been told that Pollen's ramifications are extraordinary and his newspaper influence very considerable and his being a Roman Catholic of immense support to him. I have consistently refused to have anything to do with him or see him.[179]

Pollen had previously estimated that the trial instruments would cost about £6,800. Now, apparently forgetting the prospectus claim that the instruments were 'no longer in a tentative stage', he declared that a complete set could not be delivered until well after secrecy expired in November 1909. He demanded £4,150 for additional gear plus £6,540 to extend secrecy for another year, while blaming the increases on the Admiralty for delaying a decision and demanding more extensive trials than he anticipated. The Admiralty would not entertain such an increase and asked for new prices with and without automatic sights. On 21 April, they accepted Argo's delivery dates (in June and July) and a price of £6,400 for:

> 1 Gyro-controlled Rangefinder
> 1 Charting Table ...
> 1 Change of Range Machine with transmitting and Observer's correction attachments
> 1 Set of Observer's Correcting mechanisms.

In place of sights (which almost certainly were never constructed), they asked the company to quote for the supply of two range and two deflection indicators: and agreed to pay £545 per month to prolong secrecy. A formal order was placed on 8 June, while, even though the delivery dates had already slipped, on 21 June the Admiralty invited Argo to tender for a production order of at least 30 rangefinder mountings.[180]

Just before receiving the Admiralty's acceptance of his tender, on 20 April Pollen wrote to McKenna blaming Bacon for the present delays and, with Wilson and Dreyer, for 'the farce' of the *Ariadne* trials.[181] He repeated his allegations at even greater length in the pamphlet 'Notes, Etc. on the *Ariadne* Trials', although it may not have been circulated. In any case, Bacon refused to be drawn into a quarrel. Indeed, by July there had been a remarkable improvement in relationships, when 'the D.N.O. went arm in arm with Pollen to Manchester [probably on the 8th] and came back much impressed'.[182] The Assistant DNO, Captain Arthur Craig, and Dreyer also visited the Linotype works on 12 July. Dreyer's technical report on the A C instruments was favourable and recommended that

[179] Fisher to Arnold White, 4 April 1909 in Arthur Marder (ed.) *Fear God and Dread Nought, Volume II* (London: Cape, 1952-9) pp.241. See also Fisher to George Lambert, 5 April, pp.240-1.
[180] *IDNS*, pp.164-5. Secretary of the Admiralty to Argo, 21 April 1909 in T. 173/91 Part VII. There are no indications that the observer's correcting mechanisms were ever completed.
[181] Pollen to McKenna, 20 April 1909 (*op. cit.*).
[182] *PP*, p.195. *IDNS*, pp.169-71.

all were well worth a trial; this was endorsed by the ADNO, though he hoped 'the prices can be made more reasonable', and he was not very impressed by the clutch-operated training gear of the rangefinder mounting.[183] On 16 July, Bacon wrote to Pollen:

> I sincerely wish you every success with your apparatus....My definition of success may be too flavoured with a hatred of complications but this will do no harm as an antidote.[184]

Yet Sumida alleges that, as late on 21 June, 'the Ordnance Department retained both the means and the will to prevent a fair trial,' his main ground being that, on 4 June, Pollen protested to the Admiralty because 'the trials would again take the form of a competition with service equipment, that he and his employees would be excluded from the ship during trials and that he would not be allowed to test his gear at sea or train officers in their use before the trials'. In fact, in the Admiralty letter of 21 June, he was assured that thorough training would be arranged for:[185] Moreover, since Pollen had declared that the gear was no longer experimental, the Navy was entitled to insist that it be worked only by Service personnel. And, furthermore, the secrecy agreement was due to expire in only five months, unless extended temporarily month-by-month. Thus exclusion was no more than a continuation of the cautious policy first laid down by Jackson and Jellicoe in August 1906 and expressed most recently in the February letter to the Fleet.[186]

The rangefinder mounting, transmission equipment and straight-course plotter were eventually delivered to *Natal* on 21 September. Plotting exercises were conducted during October and, by the end of the month, *Natal's* Captain, Frederick Ogilvy, was impressed by what Pollen had already achieved and urged him to make the plotter helm-free.[187] Pollen later alleged that:

> Save on the first day [our gear] was put together, I have not been permitted to see it running.

Sumida accepts this at face value, but himself provides several instances of Pollen writing from *Natal*. It was not until 10 November that Pollen and Isherwood were ordered off the ship before the start of gunnery exercises. Further successful tests were then made until,

[183] Dreyer before RCAI, T.173/547 Parts 16, p.40 and 17, pp.59-61. Unfortunately, Dreyer's report was only introduced at the hearings and a copy was not included with the other written evidence.
[184] *IDNS*, pp.171.
[185] *IDNS*, p.166.
[186] The letter emphasised the 'importance of observing strictly the regulations as to the secrecy of fire control apparatus'. *Record of Business* (*op. cit.*) p.9.
[187] *IDNS*, pp.171-2.

apparently as a results of mishandling, the gear broke down. An Argo engineer was then allowed back on board 'to make repairs and to supervise subsequent operations'.[188]

Once ashore, Pollen was able to resume negotiations on a contract to supply his instruments in quantity. On 23 June, he had responded to the Admiralty's invitation to quote for the supply of 30 rangefinder mountings with a price of £1,915 (with indicators), though he also proposed a royalty of £250 per ship per annum.[189] In November, Bacon advised his successor, Captain Moore:

> The really useful portion of Mr. Pollen's apparatus appears to be the gyroscopically controlled range-finder....but there is no reason why he should be paid any large royalties on the instrument....If Mr. Pollen can be put on the same basis as all other Admiralty contractors a difficulty which has existed for the last two years would be successfully removed.[190]

On 10 December, at a meeting with the ADNO (Captain Craig), Pollen was invited to quote for 75 rangefinder mountings with indicators and for 50 plotters; while he asked for a fixed royalty of £1,000 on each mounting or table. He also revealed that the Linotype Company had quoted only £275 for the manufacture of each mounting with transmitters: and that 'it cost about £5,000 to £6,000 a year to run the Argo Co.'. He also proposed that:

> ...if the Admiralty saw its way to paying £20,000 in advance, it would enable Mr. Pollen to obtain a Controlling interest in the firm of Cooke & Son of York, where the apparatus could...be manufactured under Mr. Pollen's direct control.[191]

This meeting was held six days before Moore took up his position as DNO,[192] while Wilson was about to supersede Fisher as First Sea Lord. In October 1909, apropos the latest Battle Practice, Fisher had gloated that 'the new system of Fire Control is quite excellent and knocks Pollen into smithereens'; yet Pollen seems to have been unaware that he was in Fisher's black books and feared that Wilson would be hostile. However, in the following March, 'Pollen appears to have been told [probably by Jellicoe] that Wilson's opinions were not the obstacle that he had supposed'.[193]

[188] Pollen to the Secretary of the Admiralty, 13 April 1910, T.173/91 Part VII. *IDNS*, pp.172-5 and 183. At the RCAI hearings, Pollen's counsel accepted that Pollen had been present on *Natal* until November: T.173/547 Part 8, p.63.
[189] *IDNS*, p.165. *Record of Business*, p.10.
[190] *Paper prepared by the Director of Naval Ordnance for the Information of his Successor*, November 1909, p.4.
[191] 'Pollen Aim Correction System. Notes of what took place at the Conference...on...10th December 1909' in T.173/91 Part VII. The Linotype Company, which made Pollen's early instruments, had come under American control: Pollen's counsel to RCAI, T.173/547 Part 8, p.74.
[192] Service record, ADM 196/42 p.64.
[193] *IDNS*, pp.161, 174-5 and 197-8.

Moore followed Bacon's advice, further negotiations focusing solely on the mounting, with transmitters and range and bearing indicators, and on a single inclusive price for each set. On 22 January 1910, Pollen proposed £1,750 each for 75 sets supplied over five years with monopoly,[194] a price to which he then held through most of the following negotiations (XIV-5). Even after allowances for contingencies, the very large difference between the manufacturing and selling costs may well explain the 'fraudulent contractor theory' apparently held by some in the Admiralty. In January, the Admiralty had warned Pollen that no decision could be expected before the start of the next financial year[195] but their opening counter-offer, of 11 April, was for only 15 sets at £1,000 each, without secrecy.[196] Following the advice of Jellicoe, who had returned to the Admiralty as Controller, Pollen's formal rejection was temperately worded:[197] but in a private letter to the First Lord, also dated 13 April, he declared, not for the first time, that:

> We have never contemplated giving foreign - and perhaps hostile - governments the benefits of the experience and skill we have acquired at the cost of the British Admiralty...unless...we were driven to do so by compulsion.

He also sought an advance of £25,000 since:

> ...owing to my having understood before Xmas, that an order for 75 units was virtually decided, I entered...into an obligation to acquire a share in an important factory...and have consequently to find £15,000 before June 15th.[198]

Even before writing to McKenna, Pollen had expressed his disappointment in a letter to J A Spender, the editor of the Liberal *Westminster Gazette*, which ended with much the same implied threat which he had used a year earlier.

> P.S.
> You know the grounds I have for being quite certain that the giving up of the monopoly will be raised by the Front Opposition Bench in Parliament, and in the Press.

Since this letter is now in the McKenna Papers, it evidently reached the person for whom it was really intended. However, it did not produce the desired effect and, after a meeting on the 19th, McKenna received another letter leaving him in no doubt of the consequences if Pollen did not get his way.

[194] *IDNS*, pp.197-8. Minute by Director of Navy Contracts to Controller, 18 April 1910, p.1 in MCKN 3/15.
[195] *IDNS*, pp.197-8.
[196] Secretary of the Admiralty to Argo Co. 11 April 1910 in T.173/91 Part VII.
[197] *IDNS*, p198. Pollen to the Secretary of the Admiralty, 13 April 1910 in T.173/91 Part VII.
[198] Pollen to McKenna, 13 April 1910 in T.173/91 Part VII.

> As the responsibility for the Board's decision to abandon secrecy and its defence in public will fall on you alone...you ought to know why this interest [in secrecy] is so great.

However, Pollen also offered some reduction in price, proposing £1,600 each for 45 sets.[199] Meanwhile, Jellicoe had asked the Director of Navy Contracts (DofC), F W Black, to recommend what would be a fair price. Black concluded that, without secrecy, a price of £1,200 would be necessary to yield a 'substantial and liberal' profit.[200] By 27 April, the parties were close enough for the Admiralty Board to give its general approval.[201] On the 29th, Argo were sent the Admiralty's offer to purchase 45 sets over the next three years at £1,350 each, while secrecy was to be maintained until the end of 1912; the first £15,000 of the value of the contract was to be paid in advance. The price covered payment by the Admiralty of all the Argo Company's charges of £6,000 per annum for the three years. In consequence, any other parts of the A C system would be supplied at the cost to Argo plus 'a fair commercial rate of profit only'.[202]

Although the 'Argo Company accepted the conditions "without qualification" on the day they were offered', Sumida proposes that:.

> ...Pollen's acceptance of the Admiralty's unfavorable terms of purchase for only a portion of his fire control system...provided a margin of profit that was too small to enable the Argo Company to carry on experimental work on the remaining instruments...[203]

In fact, there was little difference between Black's estimate of the manufacturing cost of each mounting (£600) and that actually achieved (£645, which included Cooke's profit of 30%). Therefore the Admiralty were offering a good 'ordinary trading profit' but, in addition, were prepared to pay Argo's running costs, at the rate of expenditure declared by Pollen, while the remainder of the A C system was developed;[204] thus their terms were by no means ungenerous.

With the production order settled, Pollen and his colleagues were able to prepare for the trials aboard *Natal*. Once again, after the preliminary tests, the Argo representatives were ordered off the ship. Pollen made a formal protest, but, apparently

[199] Pollen to Spender, 12 April 1910: Pollen to McKenna, 19 April 1910 with Enclosure, 20 April 1910: in MCKN 3/15.
[200] DofC, 18 April 1910 (*op. cit.*) p.6. On the same day, the DNO provided his own similar estimates (also in MCKN 3/15) in which the corresponding figures were £470 and £85; however, he used Pollen's estimate without contingencies but assumed, wrongly, that it did not include a manufacturer's profit of 25%.
[201] *Board Minutes, 27 April 1910*, ADM 167/44.
[202] Secretary of the Admiralty to Argo Co. with enclosures, 29 April 1910 in T.173/91 Part VII.
[203] *IDNS*, p.201.
[204] *Record of Business*, p.17. DofC, 18 April 1910, p.6

forgetting earlier boasts that the system would be 'ready for war',[205] admitted that the instruments could only be run reliably by his own engineers. The Admiralty insisted on the trials, which were to make comparisons with Service methods, being carried out by naval personnel; Pollen's recent threats to take his system and experience to 'foreign - and perhaps hostile - governments' confirmed yet again that he could not be trusted with Service secrets.

NATAL TO ORION

Pollen, like Isherwood, was quick to appreciate the significance of the rate plotting experiments being made by Plunkett in *Natal.* To the concern of Lieutenant Joseph Henley, now the DNO's assistant responsible for fire control, by 13 August he had declared that he was preparing 'a scheme for Automatic Time and Ranges Plotting'.[206] By November, he was also describing a time-and-bearing curve and the use of a Dumaresq-like linkage by which 'the two rates could be resolved into speed and course of the enemy'.[207] Since discussions were still proceeding on modifying the *Natal* table for dual-rate plotting, on 20 December, the Admiralty took the precaution of informing Argo of 'an instrument for automatically plotting Time and Range and Time and Bearing, devised by another inventor...and protected by secret patent'. The company was also asked whether their receivers could be adapted to work rate plots. In his reply, Pollen displayed an over-eager interest in Dreyer's rate plotter:

> ...we shall be very glad to be informed of what his means of plotting are, so that we can give you finished designs for experimenting with it....it is a matter of entire indifference to us...whether we use the inventions of others or our own.

This most uncharacteristic declaration could not in a moment reverse the Admiralty's wary attitude to Pollen.

> You have asked for certain particulars of the...invention...but my Lords...do not see their way to complying...as the secret invention goes a good deal further than the plain Time and Range and Time and Bearing which your Company propose to fit in HMS "Natal" and their Lordships prefer that the two methods should be developed independently and then tried in comparison with each other. [208]

[205] Pollen to McKenna, 20 April 1909 in T.173/91 Part VII.
[206] Henley to Dreyer, 13 August 1910 in DRYR 2/1 (Appendix XXI).
[207] *PP*, 'Quest of Rate Finder' (1910) p.269. This linkage was patented (7,382/1911); it was not itself suitable for use in a clock and it was not subsequently regarded by Pollen as important, even though the patent was not reassigned to Argo: Secretary of the Admiralty, 30 April 1913 and Argo, 'Memorandum' (1913) (*op. cit.*). The linkage was 'substantially the same invention as the Dumaresq': Pollen's counsel before RCAI, T.173/91 Part 12, p.103.
[208] DofC to Argo, 20 December: Pollen to DofC, 22 December 1910 and Secretary of the Admiralty to

Although the modified *Natal* plotter was not a success, the same policy was extended first to the Argo rate plotter and later to the clock. On 2 May 1910, Argo were invited to quote for a rate plotter, though they were also reminded that it would be covered by Admiralty secret patents; their price for the plotter that was subsequently tried in *Orion* was £550.[209]

By the end of 1911, the Argo Clock Mark III was also nearing completion.[210] On 7 December, while the DNO submitted that five ships should be equipped with Dreyer instruments, he also noted that it had already been decided to fit *Orion* with the Argo plotter and clock: even though the rough estimates of costs were £1,200 for a complete Argo installation compared with £300 for the Dreyer.[211] On 11 December, the Controller (now Rear-Admiral C J Briggs) minuted that:

> Before committing ourselves to one type of instrument I think it would be desirable to carry out comparative trials with the two systems and I suggest Argo Co. should be requested to quote a price.

This prompted the drafting of a letter to Argo requesting a quotation for one trial clock and for a further five sets; this draft was concurred in by Moore on 18 January 1912.[212] However, as soon as the clock had been demonstrated at the Argo London offices, on 18 March Pollen offered to loan it for trials, so the question of purchase of the prototype did not then arise. On 10 April, he was informed that Moore would recommend the adoption of the Argo clock for the next five capital ships to be completed, subject to the outcome of the trials and an agreement on prices.[213] However, the subsequent negotiations were to be dominated by a crisis in the company's finances which had its roots in decisions taken in 1909 and 1910.

During the RCAI hearings in 1923, Pollen and Argo presented a set of accounts which had been prepared from the company's books for the six years ending 31 December 1913 (Appendix XV). It shows investments of £12,650 at the end of 1910, increasing to £15,650 a year later.[214] Thus Pollen had carried out his intention of obtaining a major holding in Thomas Cooke and Sons of York. The shares gave him an interest in the manufacturers of his instruments as well as access to Cooke's rangefinder

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Argo, 19 January 1911 in T.173/91 Part VII.

[209] DofC to Argo, 2 May 1911 in T.173/91 Part VII. *IDNS*, pp.205 and 274 and *Record of Business*, p.15.

[210] Argo to the Secretary of the Admiralty, 17 November 1911 in T.173/91 Part II.

[211] DNO's minute, 7 December 1911 in T.173/91 Part III.

[212] Typed transcript of draft letter, DNO's marginal note and Controller's minute in T.173/91 Part IV.

[213] *IDNS*, p.221

[214] Rae Smith, 'Argo' with attached statements.

expertise.[215] However, they also tied up funds which could otherwise have been used to meet some of the large commitments, to design and manufacture, which lay ahead. The accounts confirm that Argo's expenses in 1909 were indeed close to the £6,000 estimated by Pollen: but, thereafter, they increased each year to a maximum of £12,807 in 1913. At first, Pollen was able to raise sufficient funds by means of bank loans (which reached £13,730 by 1911) and, in 1911, by the issue of Preference shares, which made £11,700. The share offer had been backed by letters from a number of prominent naval officers, including Vice-Admiral Prince Louis of Battenberg and Rear-Admiral Richard Peirse;[216] long afterwards, Peirse admitted:

> I told him [Pollen] I should be only too pleased to give him my opinion in writing if it would help matters in the way of raising capital....I may say I very much regret if my opinion misled any money [*sic*][217]

Despite these cash injections, by December 1911 there were clear signs that Argo were experiencing a significant cash-flow problem.

> ...Argo company appealed to the Admiralty to pay for the first 15 sets in full, as delivered, instead of deducting from the price of each a proportion of the 1500l. advanced....[218]

The Admiralty agreed, but, when Moore attempted to obtain a price for five clocks in April 1912, Pollen's response suggests that Argo were still in difficulties. Having declined 'to quote because it is impossible to make so small a number at commercial prices', he suggested three alternatives.

> The first is for the Admiralty to acquire the monopoly of our system, the second is to tell us at once that we are free to supply our devices elsewhere and the third is to give us a sufficiently large order for plotting tables, rangefinders [presumably he meant the Pollen-Cooke model] and mountings to enable us to raise the capital requisite for manufacturing the clocks on a commercial basis.

On 20 April, Moore assured Pollen that he intended to place an order for five clocks 'without waiting for results of the trial one': but, the 22nd, Pollen responded by proposing an order for some 170-180 clocks, enough for one in every transmitting station and every turret of all dreadnoughts built and building.[219] This might seem a surprising expectation, except that discussions were probably already taking place on ways to improve local

[215] Anita McConnell, *Instrument Makers to the World* (York, 1992) p.74.
[216] Rae Smith, 'Argo', Balance Sheet. *IDNS*, p.208; p.272 footnote 129 implies that the 250 shares were all sold and 100% paid.
[217] Peirse before RCAI, T.173/547 Part 9, pp.37-8.
[218] *Record of Business*, p.15.
[219] *IDNS*, pp.221-2.

control in turrets. A month later, an Admiralty conference attended by Moore recommended that both the Argo clock and 'somewhat modified' Dreyer apparatus could be suitable: while, as late as 7 August, commanders of the Home Fleet were advised that both instruments were to be included in comparative trials of local control arrangements.[220] Thus, on 7 June, Argo were asked to quote for clocks and rate plotters in numbers up to 96 each. Separate figures were requested with and without the maintenance of secrecy. Without secrecy, for five clocks and five plotters[221], they quoted £2,400 and £500 each, respectively, the prices falling to £1,350 and £400 for quantities of 96 each. However, the company refused to quote for the maintenance of secrecy either for a limited period, or for only a part of the system, which 'must be regarded in its entirety'.

Meanwhile, Argo's financial crisis appears to have deepened further, since, on 13 May:

> They...asked the Admiralty to pay them an additional 26,000l. or else to release them from secrecy obligations in advance of the agreed date so as to enable them to raise capital outside.[222]

However, the Company's request led to an examination of Argo's books. Expenses were considerably heavier than those estimated in 1910, due to the 'high salaries to directors and skilled designers &c [while] a large part of their work was upon other features of the A.C. system not included in the 45 sets': and also to high spending on experimental and prototype gear and on offices.[223] The company also claimed that it 'was about 8000l. to the bad at the time when the order for the 45 sets was given'; yet Pollen himself admitted to being at least £5,700 to the good in May 1908; Argo also represented the purchase of the shares in Cooke's as an expense rather than an asset.[224] By 23 July, Pollen announced that his financial embarrassments had, somehow, been resolved, while by the end of the year, with the mountings delivered, Argo was once more in profit.[225] Thus, in attempting

[220] DNO and ITP, 'Local Control in Turrets' 24 May and Secretary of the Admiralty to Officers Commanding Home Fleet, 7 August 1912 in 'Important Questions dealt with by DNO', Vol.I - 1912, AL.
[221] Described as 'Range Plotters only - that is, Range and not Bearing Plotters'.
[222] *Record of Business*, p.17. Contrary to the impression given in *IDNS*, pp.201 and 222, the contract for the mountings did not give Pollen any right to renegotiate the price.
[223] Pollen had awarded himself £2,500 and Isherwood £1,000 per year. For comparisons with Admiralty salaries, see XIV-6.
[224] *Record of Business*, pp.14 and 17. The 1923 accounts show an accumulated loss at the *end* of 1910 of £5,558 but, as explained in Appendix XV, this was not a true representation of the Company's profitability.
[225] *IDNS*, pp.222 and 276. Rae Smith, 'Argo' with Profit and Loss Account. The profit in 1912 was £15,081 while the accumulated profit since 1908 was £1,991.

to justify additional payments, Argo appear to have exaggerated their losses. Unfortunately, the outcome was the opposite of that intended, since they succeeded in convincing the Admiralty that 'there had been serious extravagance in expenditure'. On 22 June, the firm was informed that 'the Admiralty [had] decided not to pay the extra 26000l. ...and not to release the Company from the agreed period of secrecy'.

Moore (now a Rear-Admiral) was about to join the Board as Controller, while his successor as DNO was Captain F C T Tudor. Despite Argo's difficulties, there was no change in the policy on trials.

> It is proposed to purchase five Argo clocks combined with automatic time and range plotters for the "King George" class, to enable a very thorough comparative trial against the Dreyer gear to be carried out.[226]

But, after Pollen had himself asked twice to be released from secrecy:

> ...the question of whether it is worth renewing it is under consideration. It is desired to treat the Argo Company similarly to all other contractors, and to dispense with secrecy agreements in future as far as possible.[227]

When the question was raised:

> The Argo Company offered to continue secrecy for 5000l. *per month*...
> ...They suggested the Admiralty should make them an offer for permanent secrecy or refer it to arbitration. From conversations, however, it was clear that the Company would want much more than the 140,000l. conditionally agreed...in 1908...

Thus, Argo's 'exorbitant terms'[228] left no reasonable alternative but to dispense with secrecy, a policy which also promised to bring down Argo's prices.

After he became Controller, Moore retained responsibility for the negotiations with Argo, as might be expected given his familiarity with the case and Pollen's habitual lobbying at the highest level. However, Sumida proposes that Moore 'was determined to block the advance of the Argo Company' and resorted to 'underhand action' to damage Pollen's standing with members of the Board.[229] The reality, as shown by his minute of 13 August (Appendix XVI), was that Moore was now openly determined that the secrecy agreement with Argo must end.[230] Although there is no record of discussion at a formal Board meeting, Moore's advice was accepted and, on 20 August, Argo were informed that

[226] *DNO for Successor* (*op. cit.*) 30 May 1912, p.13. Moore presumably meant the four *KGVs* and *Queen Mary* of the 1910-11 programme.
[227] *ibid.* p.12.
[228] *Record of Business*, pp.17-8.
[229] *IDNS*, pp.223-4 and 276-7. However, the principal source is an unsent letter to J A Spender drafted by a disappointed and angry Pollen nearly three months after the event.
[230] A G H W Moore, Extract from 3rd Sea Lord's Minute in MB1/T22/174, Papers of Prince Louis of Battenberg in Mountbatten Papers, University of Southampton Library: reproduced in Appendix XVI.

monopoly and secrecy would cease on 31 December and that arrangements would be made for the prompt reassignment of patents; a new quotation for five clocks was requested 'at a price greatly below the £2,400 originally quoted'.[231]

As on previous occasions, Pollen's response was to lobby hard to have the Board's decision reversed. In his support, Rear-Admiral Peirse wrote to the Second Sea Lord, Prince Louis of Battenberg, who in turn asked Moore for his comments.[232] Moore's handwritten letter of 19 September (also in Appendix XVI) repeats and expands on the points in his minute. His view was that, as Pollen gained more confidential knowledge, he could press for yet higher monopoly prices and that it was time to shake off 'a chain being forged...more and more relentlessly'. Moore considered that the rival fire control systems were functionally about equal: except that, while he was prepared to try Argo's new true-course plotter, he remained sceptical that Pollen would be any more successful than he had been previously. But Moore also emphasised that:

> I am so far from being opposed to Pollen's Clock that I have begged him for his own sake to push on with it & perfect it, as I knew Dreyer was going ahead & I believed Argo Company's work would be more accurately carried out. I have been for nearly a year trying to get contracts placed for 5 Argo Clocks...but Pollen has held out always on a prohibitive price based on Monopoly terms.[233]

The Admiralty quickly discovered the difficulties of shaking off Pollen while maintaining secrecy on the dual-rate principles embodied in the Dreyer Table. Beginning in September, Argo began the process of patenting their course and rate plotters and, despite the Admiralty's request to withdraw the application for the latter, it was registered as a provisional specification on 12 October.[234] At a conference with Commander C V Usborne[235] on the 15th, Pollen further declared, on the basis of the mention of range-rate plotting in 'Reflections on an Error of the Day' and the adaptation of the *Natal* table to dual-rate plotting, that he had invented rate-plotting independently and that the Admiralty had no claims which could invalidate his application. He did undertake to keep rate-plotting secret until it was made public by some other source,[236] but this was of only

[231] Secretary of the Admiralty and C A Oliver for DofC to Argo, both 20 August 1912 in T.173/91 Part VII.
[232] *IDNS*, p.227. Peirse to Battenberg, 7 September 1912, MB1/T20/142.
[233] Moore to Battenburg, 19 September 1912, MB1/T20/147. Excerpts in *IDNS*, p.227.
[234] Patent 23,351/1912.
[235] Now the DNO's assistant responsible for fire control.
[236] Pollen to DofC, 25 November 1912 in T.173/91 Part VII.

temporary value, since, while the provisional specification would not be published, it was the initial step towards open publication as a Complete Specification.[237]

Following his usual practice, in June Pollen had already opened a correspondence with the First Lord, now Winston Churchill, to protest that secrecy was not to be renewed. On 21 October, he sent Churchill an all too characteristic letter. Pollen began by damning the Service system which he had seen while demonstrating the Argo gear in *Orion*, thereby confirming that it was impossible to keep Service secrets while he and his staff were allowed aboard. Then, confusing present capabilities with possible future improvements, he claimed that his clock could keep the range 'with perfect accuracy...when we are under helm with the target obscured': which was not true either of the Mark III or Mark IV clock. And, he threatened that:

> The day my system becomes public property you have no secret of any kind left in your naval gunnery. In as far as you have adopted a restricted and mutilated form of my system you have obviously no secret of any value.[238]

Yet, despite Pollen's claims and threats, the Admiralty persisted with the intention of purchasing five more clocks for comparative trials; on 26 October, even before the successful trials in *Orion* on 19-20 November, a not greatly reduced price of £2,133 for each clock was agreed.[239] Meanwhile, Churchill, like his predecessors, appears to have had second thoughts about ending Argo's monopoly agreement. On 6 December, during an interview with Pollen's brother, Colonel Stephen Pollen, Churchill requested a quotation 'for a large number of Clocks, the price to be calculated on the basis that the Admiralty should be our only customer'. Moore, who was also present, acknowledged that the Argo clock was mechanically superior, but insisted that its price and the price for monopoly were excessive. Nonetheless, on 11 December Argo quoted £1,600 each for 150 clocks to be supplied over the next three years, £50,000 to be paid in advance. Battenburg informed Pollen that, with such prices, there was 'no possibility of coming to an agreement'.[240] The Director of Navy Contracts noted that Elliotts won the order for five range-rate plotters (for use with the five Argo clocks) with a price of £138.10.0: while their price for five complete Dreyer tables (which combined two rate plotters and a clock) was only £635 each. He therefore urged that the earlier decision to end monopoly should

[237] T H O'Dell, *Inventions and Official Secrecy* (Oxford, 1994) Chapter 6 (reference courtesy of Dr. Anita McConnell).
[238] Pollen to Churchill 24 June and 21 October 1912 in T.173/91 Part II.
[239] *IDNS*, p.229. The *Orion* clock was purchased later at the same price: *Record of Business*, p.16.
[240] *IDNS*, pp.233-5.

be adhered to.[241] On 19 December, Argo's offer was declined and the decision to end secrecy confirmed; any future orders were not ruled out but they would only be placed on 'ordinary commercial terms'.

1913-1918

Although the patent for the rate plotter remained contentious (Argo were warned that it might fall within the scope of the Official Secrets Act),[242] there was for a moment a chance that Argo might establish a new relationship as a normal Admiralty supplier. On 10 January 1913, Pollen informed the DofC:

> ...we have now completed the jigs and special tools necessary for manufacturing Argo clocks in quantities and are therefore able to make you a more favourable quotation than that submitted some six months ago...
> £1150 in lots of 25.[243]

Unfortunately, Pollen was also gathering letters criticising the abandonment of secrecy. While Reginald Plunkett noted on Pollen's letter:

> The request contd. in this letter, wh. I consider wrong, I replied to saying that I found it impossible to comply with'.[244]

other officers were more forthcoming and extracts were sent to Churchill by Stephen Pollen on 20 January. The letters contained direct attacks on Dreyer, Jellicoe and Moore and strong criticisms of the Admiralty, which was accused by one correspondent of 'crass stupidity'. The day after they were sent, Arthur Pollen seems to have suddenly recognised the danger and attempted to withdraw them, but the damage had already been done. On 22 January, Churchill's secretary informed Pollen that his action in soliciting criticisms from officers afloat was 'irregular', that the worst extract was 'grossly improper and offensive in its character', and that 'the First Lord was unable to reopen the question of monopoly or the clock'. Then, on 4 February, Pollen approached the Conservative E G Pretyman, a former Financial Secretary to the Admiralty, with a view either to raising his case privately with the Prime Minister or 'making a front bench question of it'. Pretymen consulted Jellicoe (who had returned to the Admiralty as Second Sea Lord) and then

[241] Minutes 'Pollen Aim Correction System' (initialled by Churchill): and 'Argo Company, Present Situation' with 'Details of Clocks and Rate Plotters on order' by F W Black (DofC), n.d. but December 1912 in MB1/T22/174.
[242] Secretary to Argo, 19 December 1912 in T.173/91 Part VII and in MB1/T22/174.
[243] Pollen to DofC, 10 January 1913 in T.173/91 Part II.
[244] Pollen to Plunkett, 17 January 1913 in DRAX 3/4.

declined to take any further action.[245] After these incidents, there were no further discussions about additional orders.

In January, the DNO, Tudor, began to take a more active part in dealing with Argo, initially by raising with Pollen the concern that the clock features for setting the bearing rate gave a clear indication of the Admiralty's dual-rate system.[246] On 18 February, Tudor opposed a suggestion by the DofC, F W Black, that Pollen might be persuaded by a payment for services rendered to forego sales to foreign governments. Sumida suggests that:

> Tudor's views carried the day and his scheme for obstructing the foreign sale of the Argo Clock officially adopted.[247]

In fact, after Pollen's recent crass attempts to force changes in policy, it is unlikely that he had any support remaining in the Admiralty: while the question of the bearing-rate dial was not just a ploy. The Navy's opinion was that the clock controls for setting range and bearing rates 'are in no way germane to the Aim Corrector system but were evidently fitted to admit of the clock being used on the Service system'.[248] Pollen maintained that they were 'merely the expression of mathematical truths' and, for good measure, that 'you [*sic*] cannot publish my system without publishing yours, because the whole of your system is involved from mine'.[249] He would yield nothing to the Admiralty's concerns and, once his lawyers became involved, the correspondence degenerated into lengthy, point-by-point claim and counter-claim.[250] Relations, already bad, grew worse, especially after the dispute became public. *The Naval Annual* for 1913, published in late May or early June, described the main features of the Argo table and clock and pronounced that:

> Mr. Pollen...has apparently succeeded in perfecting instruments of incalculable value for finding and keeping the rate at long range.[251]

In mid-June, Pollen informed editors of the end of secrecy and, from 19 June, articles of varying degrees of accuracy appeared in a number of papers, including *The Times*, whose owner (John Walter) had until recently been a major Argo shareholder. Then on 30 June,

[245] *IDNS*, pp.235-7.
[246] Pollen to DofC, 18 January 1913 in T.173/91 Part II.
[247] *Record of Business* (1913) Annex p.1. *IDNS*, p.237.
[248] Admiralty to Argo, 21 February 1913 in T.173/91, Part II.
[249] Pollen to Usborne, 29 April 1913 in T.173/91 Part VII.
[250] Correspondence between Coward & Hawksley Sons & Chance and the Secretary of the Admiralty in April to June 1913 in T.173/91 Part VII.
[251] Viscount Hythe, *The Naval Annual 1913* (Newton Abbott, reprinted 1970) pp.319-20.

a Liberal MP, Robert Harcourt, raised the matter of the Pollen system in the House of Commons, in a question to the First Lord. Sumida proposes that.

> the absence of evidence makes it impossible to establish the exact extent of his [Pollen's] involvement with the press and with Harcourt's queries

but himself acknowledges Pollen's involvement with the owner and editor of *The Times*.[252] Pollen's previous record also strongly suggests that he was behind the question in the House: and, in the unlikely event that he was not, no one in the Admiralty would have believed it.

On this, as on previous occasions, Pollen's actions had undermined Argo's efforts to reach an accommodation with the Admiralty. On 10 June, the company's Board had decided after all to omit the rate dials from their foreign patent applications, at least for the moment; but this was only communicated to the Admiralty at a meeting on 30 June (the day of Churchill's question in Parliament). The DofC then asked for more excisions and, after further exchanges, Argo concluded that 'the views of the Company and of the Admiralty are irreconcilable'.[253] By 4 August, the Argo gear had been shown 'without reservation to foreign naval Attaches'.

> The Admiralty...considered...that the action of the Argo Company was most reprehensible....all business and other relations were to be broken off with the Company and the Company's name was to be removed from the Admiralty list and the Fleet, and the Australian Navy were informed that no further intercourse was to be held with it.[254]

On 5 September, Pollen and Isherwood included the clock in their applications for French and American patents and, as the Admiralty had feared all along, described both rate dials and their use. The American patent read:

> ... means are provided for setting up either the target course and target speed or the rate of change of range and rate of change of bearing. In order to determine the target course and target speed, recourse must be had to one of the methods of plotting.[255]

Furthermore, despite Pollen's assurances in November 1912, the complete specification for the dual rate plotter had been left at the Patent Office on 13 May 1913, even before the final break; the only concessions to Admiralty concerns was that the specification (23,351/1912) did not describe a separate pencil for clock range: and the company only applied for foreign patents on its true-course plotter.[256]

[252] *IDNS*, pp.241-4.
[253] *IDNS*, pp.241 and 244-5.
[254] *Record of Business*, Annex, p.7.
[255] US Patent 1,162,510, filed 5 September 1913, p.1. French patent 464.049, demandé 5 Septembre 1913, delivré 5 Janvier 1914.
[256] US Patent 1,123,795 and French patent 464.044; dates as above.

The accounts show that, by the end of 1913, Argo had been fully paid for the rangefinder mountings and clocks. Even if Pollen's profit before 1908 is ignored, in the years 1908 to 1913, Argo made a loss of only £3,778 on receipts of some £103,000. Following a 6% debenture issue in 1913, Argo had raised a total of £23,350 in shares and debentures while their bank balance was £5,710 in the red. However, they still held shares in Cooke's to the value of £16,650 while their stock of instruments had cost £4,554; most importantly, they had completed the development of the Argo system while their only significant income had come from the Admiralty.[257] As for Pollen himself, his salary as Governing Director increased from £1,500 to £2,500 sometime between 1909 and 1911 and he continued to draw it until 1918 or 1919;[258] thus his total income was somewhere between £24,500 and £29,000. In addition, Pollen's own bank statements showed that, when Argo was registered at the end of 1907, he had already made a profit of £2,930 on his dealings with the Admiralty, while he also received Argo shares and debentures to a value of £4,399 for the assignment of his existing interests and obligations. All the debentures were redeemed in 1909, necessitating a payment to Pollen of their value of £3,500.[259] Thus Pollen was well rewarded over many years at the expense of his Admiralty contracts or, latterly, of the Argo shareholders.

The Argo Company began its overseas sales campaign in September 1913. Discussions with Turkey, the United States and France eventually foundered on questions of cost, while the French in any case preferred rate to course plotting. The Russian Navy, however, accepted Pollen's analysis and he received an order for five complete systems: although, as already mentioned, the delivery made in October 1914 was much reduced. An agreement had also been made with Austro-Hungary, while negotiations were nearly concluded with Brazil and Chile, but all were terminated on the outbreak of war.[260] However, the Russians remained convinced of the superiority of the Cooke-Pollen rangefinder, for which they placed at least one more order, for eight instruments, in 1916.

[257] Rae Smith, 'Argo', Balance Sheet and Profit and Loss. *IDNS*, p.247. In addition to the Mark V clock and the Mark IV plotter, the final system apparently included a new, two-observer mounting for the Cooke-Pollen rangefinder: *IDNS*, Plate 2.

[258] Rae Smith, 'Argo', Profit and Loss Account. 'Conference 10 December 1909' (*op. cit.*). Pollen before RCAI, T.173/547 Part 15, p.62 (XIV-7).

[259] Rae Smith, 'Argo', Balance Sheet and 'Payments made by Mr. Pollen between 1905 and...incorporation...'. The author is most grateful to Mr John Horne, FAPA for explaining how to interpret the accounts.

[260] *IDNS*, pp.247-8 and 295-6. For the Russian order, see A H Pollen, 'Memorandum on Fire Control', 1916 in T.173/91 Part II.

The Admiralty went to some lengths to obstruct this delivery,[261] showing that the bitterness left after the acrimonious break with Argo in 1913 was long-lasting.

After Jutland, Pollen produced two long memoranda arguing for his system to be reconsidered. Jellicoe submitted them officially to the Admiralty, urging in particular that the latest Cooke-Pollen rangefinder should be examined.[262] Thirty were eventually ordered in 1918, even though the report of the Phillpotts committee noted that, in tests, a 15-foot model had not shown 'any marked advantage over the Barr & Stroud rangefinder at present in use'. This committee had been convened after, for the last time, Pollen had written to an incumbent First Lord, now Sir Eric Geddes; Pollen proposed that instruments about to be despatched for trial to the United States should be inspected by the Royal Navy.[263] The committee was impressed by their 'near mechanical perfection', although they concluded that the instruments were not 'as suited to the service requirements as the present methods in use'. However, Pollen was evidently continuing to hinder his own chances of acceptance:

> Some of the knowledge and most of the experience required for the design...have been gained in H.M. Service, and it is...unfortunate that these should be made use of to the public depreciation of Service methods, for which there is no justification.

Nonetheless, the Committee concluded:

> It is a matter for regret that the ingenuity and mechanical designing ability displaced is producing these instruments have been lost to the Service....The question is for consideration whether the services of the Inventor and his Staff could be utilized in connection with the design of future fire control instruments'.[264]

In responding to the report, Frederic Dreyer, now Director of Naval Ordnance, began:

> I had hoped not to have to minute an Admiralty Docket on the subject of Mr. Pollen's Fire Control Apparatus as I am the inventor of the Dreyer Fire Control Apparatus...

He went on to concur with most of the committee's report, though he insisted that Harold Isherwood could not be spared from the position he now held at Chief Designer in the Mining School. He concluded:

[261] The First Lord made the excuse that Cooke's were seriously behind with Admiralty work; correspondence between Pollen and Balfour in T.173/91 Part VII.

[262] 'Memorandum on Fire Control' and 'Memorandum II', Enclosures 1 and 2 to Summission...of 21.8.16 from C.-in-C. Home Fleet in T.173/91 Part II. Since Jellicoe submitted the entire memoranda, he did not 'turn a blind eye to Pollen's analysis' in order to deflect criticism of his and Dreyer's part in the rejection of the Argo system: *IDNS*, pp.307-8.

[263] *IDNS*, pp.309-11.

[264] Phillpotts Committee, 'Report', p.6.

> Mr. Pollen is an enthusiast who always overstates his case...after...Jutland he informed everyone of the vast superiority of the Crooke [*sic*] Range Finder, views which were not found to be justified when it came to be tried...
> Mr. Pollen, no doubt with the very best of intentions produced a great feeling of unrest in Naval Gunnery Circles when his instruments were on trial by his whirlwind eloquence and his journalistic efforts.
> I am most strongly of opinion that it would be a grave error to once more put him in touch with the Service...

There were sufficient truths in these statements to convince the whole Admiralty hierarchy, from Geddes and Wemyss downwards. The Deputy First Sea Lord, Rear-Admiral George Hope, added a minute that:

> Mr. Pollen has always claimed that his methods would produce great results, but he has always underrated the practical difficulties to be met.

Thus Pollen had no significant support remaining in the Admiralty and he was sent a noncommittal letter expressing only polite interest in the outcome of the American trials.[265] In June, he wrote to the First Lord asking for an enquiry leading to the recognition which he believed was his due for the use by the Admiralty of his inventions: but, on 18 December, his request was rejected.[266] After this final exchange, Pollen would have to wait for the sittings of the RCAI before, eventually, receiving his reward for the Argo clock.

The collapse of Argo's commercial relationship with the Admiralty, which Pollen's own actions had done so much to provoke, prevented him from demonstrating his complete A C system to the Royal Navy. The outbreak of the War then robbed him of the opportunity to show, by successfully supplying foreign navies, that he had been right all along about the superiority of his system. But was his conviction, on which he never wavered, correct? To attempt to answer this question, it is now necessary to examine the history and development of the rival Dreyer Tables.

[265] 'Pollen Fire Control Apparatus' in 'Monthly Record of Principal Question dealt with by Director of Naval Ordnance', January to June 1918, pp. 308-310 and July to December 1918, pp.819-829. The writer is most grateful to Professor Sumida for copies of these minutes.
[266] J W S Anderson to Pollen, 18 December 1918 in T.173/91 Part VII.

NOTES.
1. The arrangement of the Dumaresq and the drives is similar to that in the clock but the runs of shafting are largely schematic.
2. The clutches are represented conventionally; the actual mechanisms were different.
3. For simplicity, the rate dials have been omitted,together with the mechanism for converting speed-across into bearing-rate.

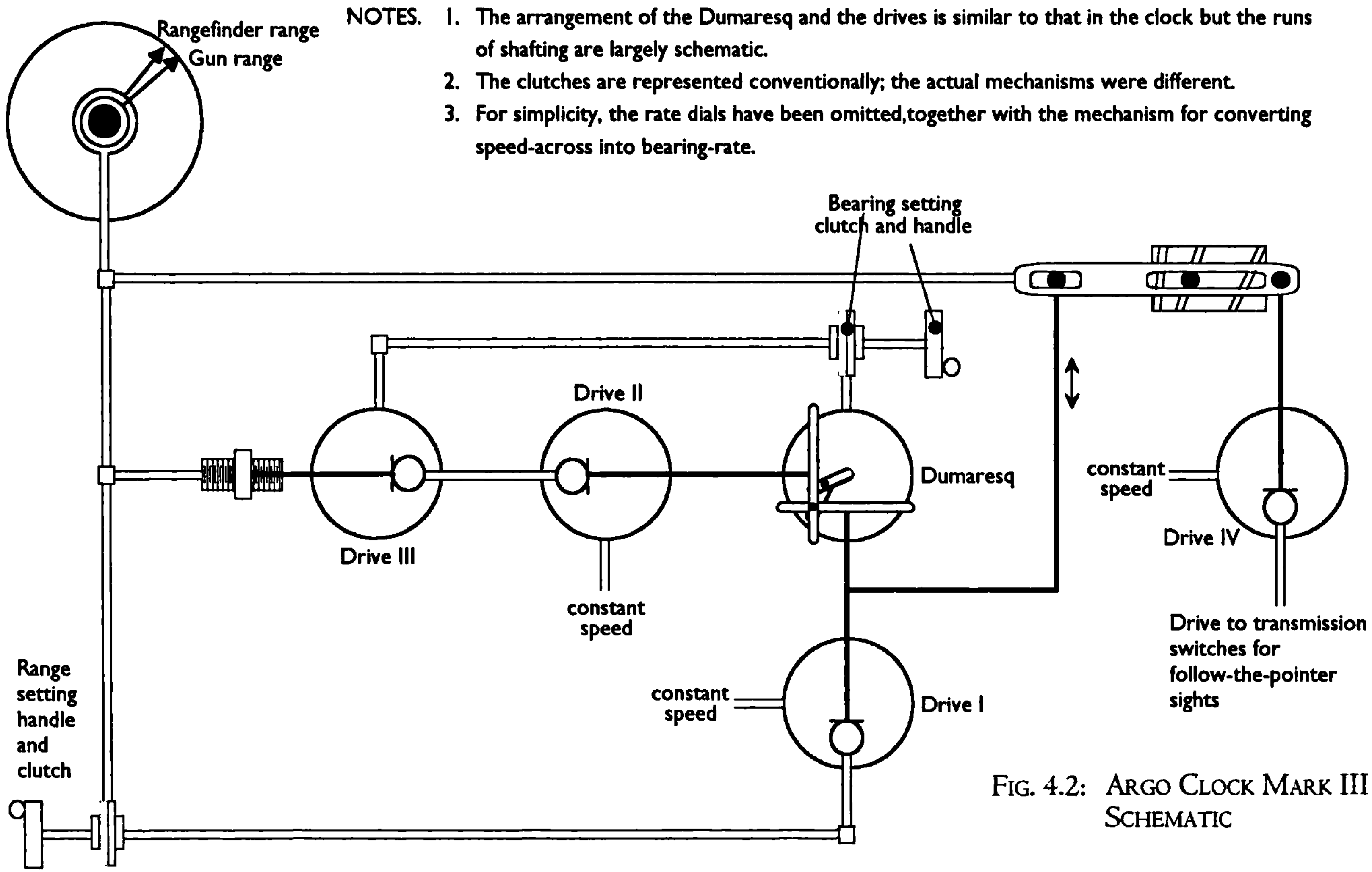


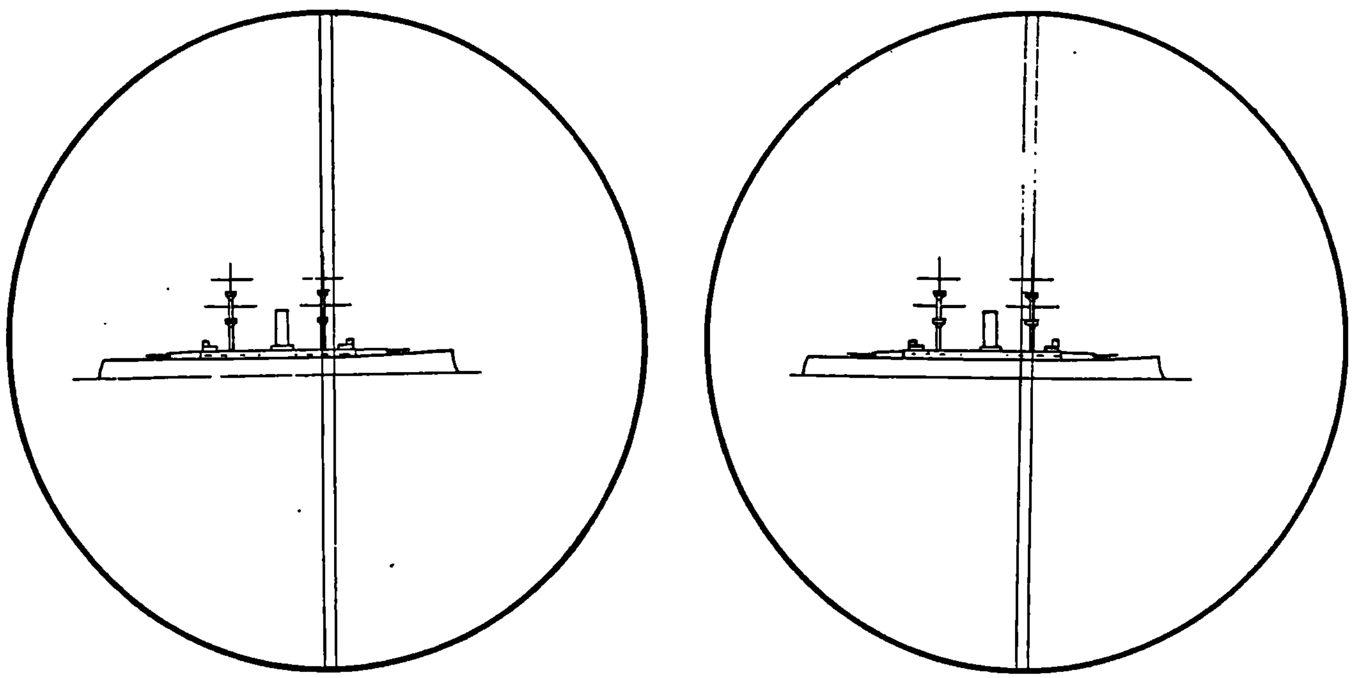
FIG. 4.2: ARGO CLOCK MARK III SCHEMATIC

Plates for Chapter 4

52 THE POLLEN PAPERS

See Section 20, 21 and 22.

FIGS. 9 & 10.



HOLD 9 INCHES FROM THE EYE.

SHOWING H.M.S "MAJESTIC" AT 10,000 YARDS.

TELESCOPE 1½° FIELD, MAGNIFYING 20 TIMES. ANGULAR DISTANCE BETWEEN HAIR LINES 1½ MINUTES.

Whenever both operators have the observed mast between, or one of the vertical lines in their respective fields simultaneously, synchronism is obtained, and the base angles are automatically registered by the indicator. Two or three vertical lines may be used to guide the eye.

10. Two-position Rangefinder: Bearing Observations

Each observer had to keep the same target feature (in this case the fore-mast) between the two hairlines, separated by an angular distance of 1½ minutes (one sixtieth of the field of view). To obtain the claimed range accuracy, he also had to envisage the band as subdivided into six 15 second intervals. The original caption proposes two or three 'guiding lines'.

By pressing one of seven keys, an observer could transmit to the calculating machine which actual or imagined line was closest to the target feature. The transmission system was supposed to record only keystrokes made simultaneously by both observers.

Pollen Papers, 'Fire Control and Long Range Firing', December 1904, p.52. Patent 11,535/1904, applied for 19 May, complete specification 11 February 1905.

A.D. 1909. March 2. N.º 5031.
POLLEN & another's Provisional Specification.

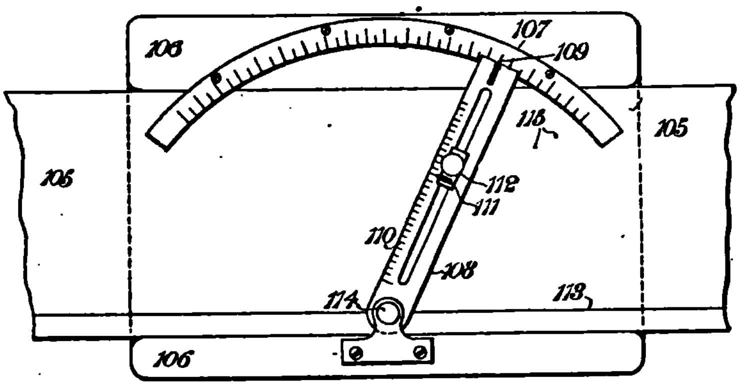
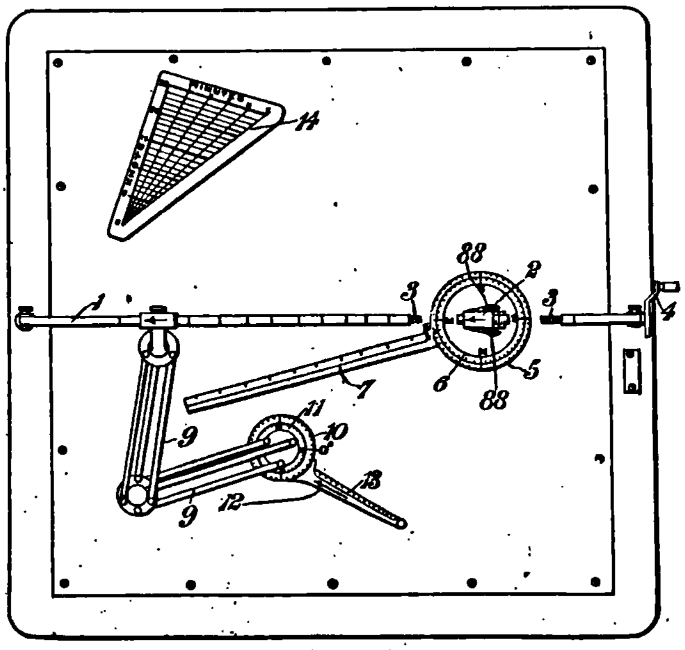


Fig. 1.

Fig. 2.



II. Straight-course Plotter (1904) and Manual Plotter (1909)

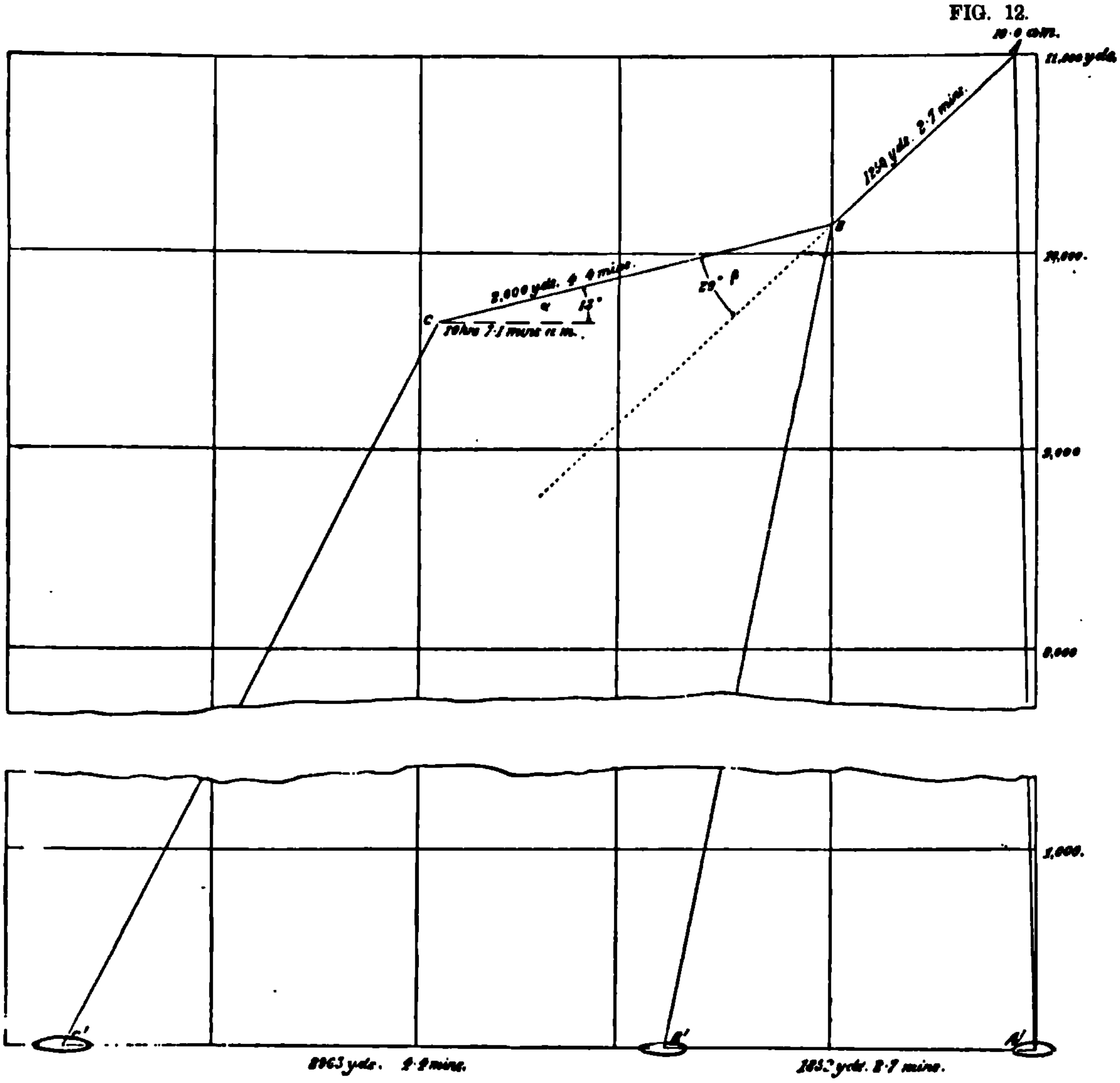
Fig. 1 was first used in patent 23,872 of 1904 and is probably similar to the *Jupiter* plotter.
The broad paper ribbon was moved by clockwork between rollers at a speed proportional to the speed of the firing ship. Own course was plotted, as a straight line down one edge of the plot, by a 'pricker' in the centre of the pivot of the plotting arm.
Target position was plotted manually with the pin sliding against the range scale on the arm. The angle of the arm was set to the bearing of the target relative to own course.

Fig.2 is the manual plotter patented in 1909. The charting paper was pinned to the board (while own course was steady). The carrier for the plotting arm and the pencil plotting own course was advanced at a speed proportional to own speed by the long treaded rod, which was by a variable-speed drive (not shown).
The scale on the parallel linkage was used to measure target course and distance travelled. If the times of the plotted target points were known, the speed could be obtained from the triangular scale.

Patent 5,031 of 1909, applied for 2 March, complete specification 13 September 1909.

See Section 25.

FIG. 12.



In the above figure the line A¹, B¹, C¹ represents own course, right to left; own speed is 40.000 yards per hour: own direction from A¹ to B¹, then from B¹ to C¹. At B¹ the course was changed by the angle *b* (29°) to port. The paper is divided into 1.000 yard squares, and travels on the table from left to right, at the rate of 40 squares per hour.

A represents the position of the enemy at 10 a.m. His course is the median line between the successive observed positions till B, at which his course apparently changes. In reality he has kept a straight course (the dotted line), but own course has been changed when the range is nearly 10.000 yards, to keep him at an advantageous distance for engaging. When C is reached by the enemy we know that his speed is 3.250 yards in 7.1 minutes—i.e., v. A to B to C, showing his speed to be 26.664 yards per hour. The rate of change machine is then set to this speed, and to the angle 13°, and will continue to give his range and bearing accurately.

The lines A¹A, B¹B, C¹C show the enemy's angular bearing at 10 a.m., 10h. 2.7m. a.m. and 10h. 4.4m. a.m.

12. Straight Course Plot, Own Ship altering Course

Although own ship alters course at B′, there is no change in the plotted target bearing; the enemy bearing continues to taken relative to own ship's original course.

Pollen's caption does not mention that the enemy course from B to C is not the actual course but a virtual course which, with the virtual bearing, gives a correct rate.

Pollen Papers, 'Fire Control and Long Range Firing', December 1904, p.54.

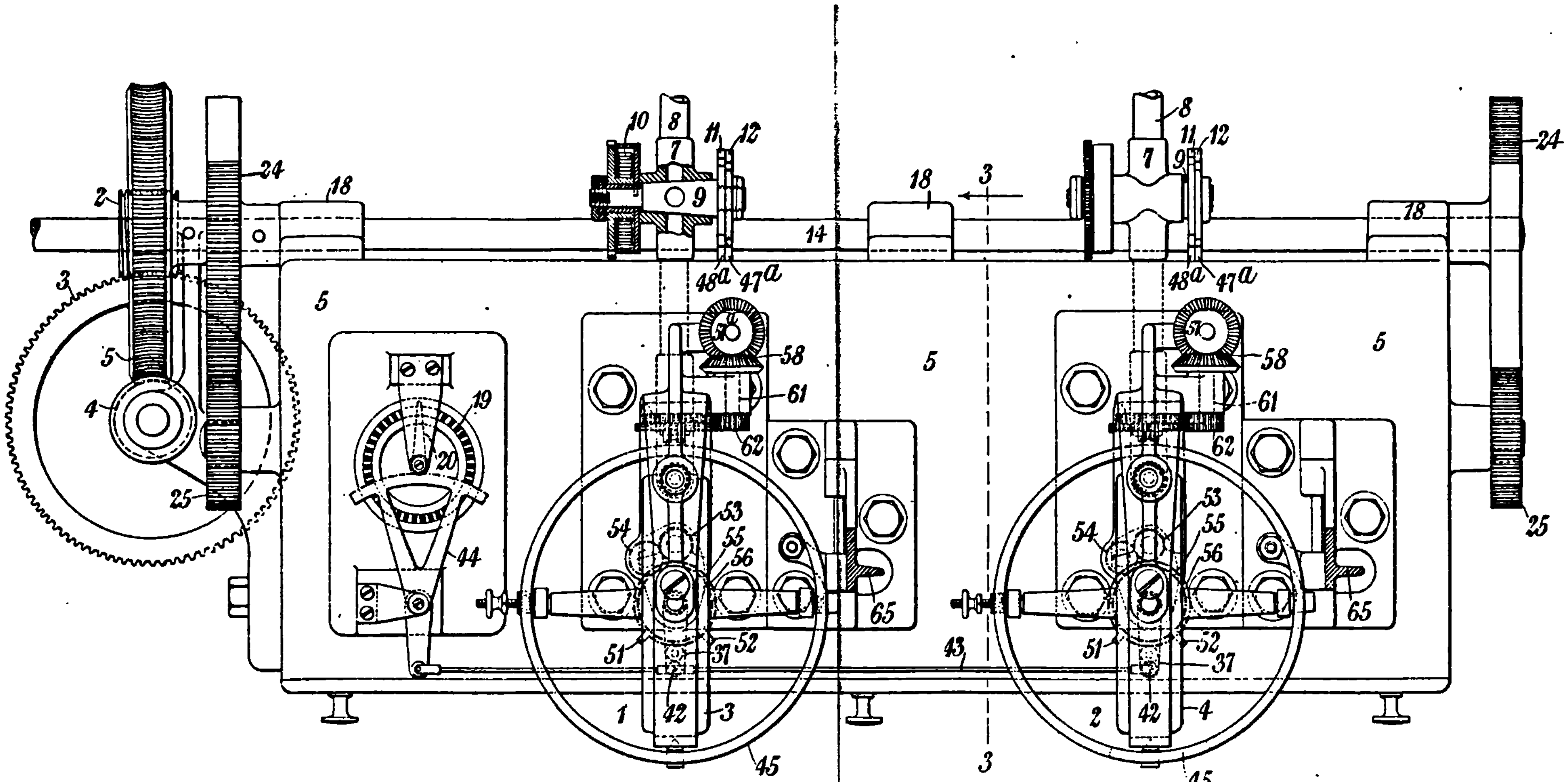
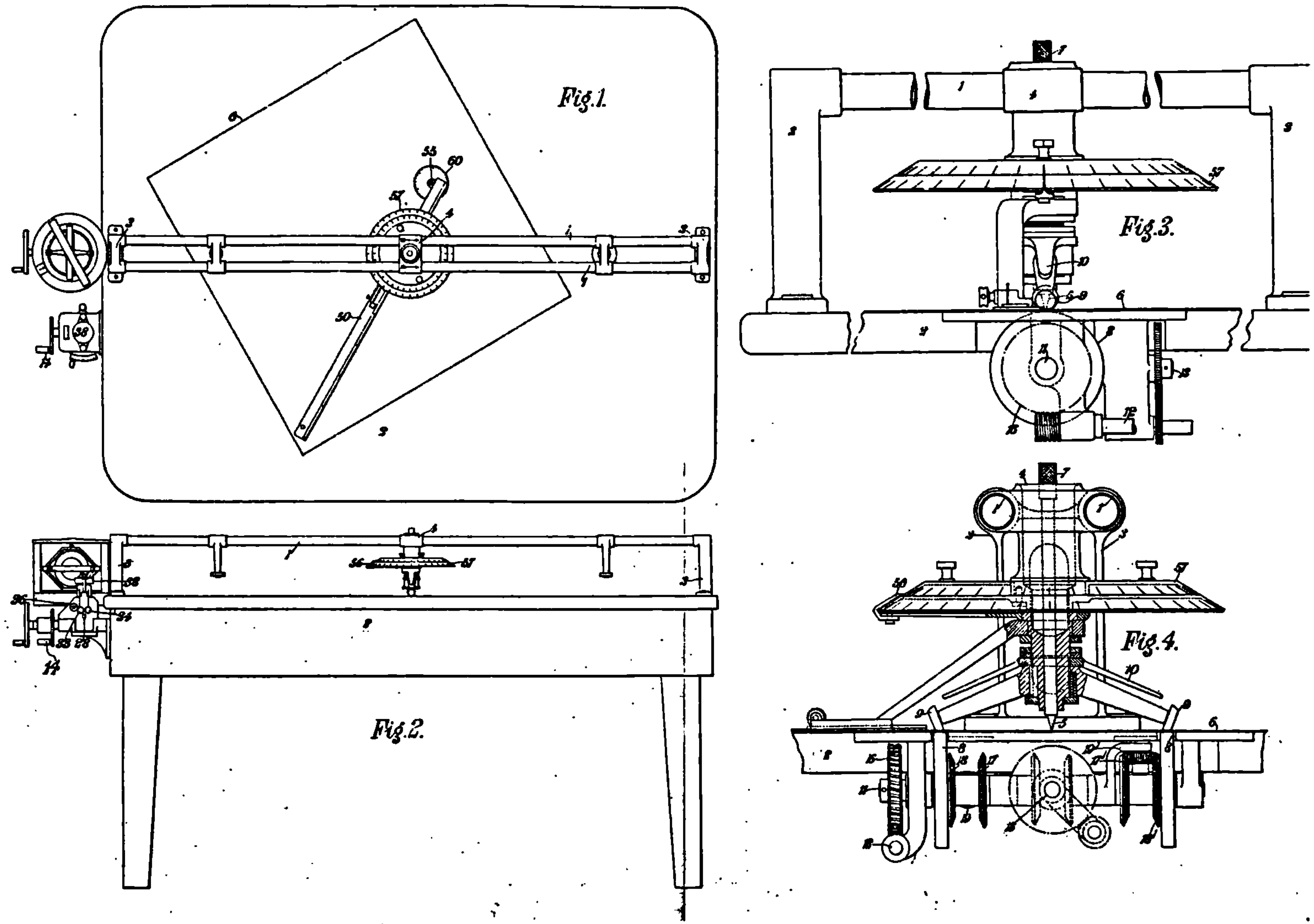


Fig. 2.

13. ARGO DUAL GYROSCOPES (SIMILAR TO THOSE IN ARIADNE)

The two gyroscopes were coupled alternatively by clutches to the arm 44; the coupled gyro held the arm fixed in space even as the ship yawed. While each gyroscope was disconnected from the arm, it was clamped parallel to the keel and driven up to speed by an air blast.

Patent 23,846/1906 applied for 26 October, complete specification 25 May 1907.



14. Argo True Course Plotter as patented in 1910.

The general arrangement is similar to the *Natal* plotter, though the method of moving the paper is quite different. In the straight-course plotter first delivered to *Natal*, the carriage carrying own-ship's pencil and the plotting arm moved on the parallel bars. In this true-course version, the carriage was stationary. The paper was driven from below (both linearly and rotationally) by a pair of wheels, one on either side of the fixed plotting point. The paper was held in direct contact with the wheels below by pressure wheels above, all wheels having rubber rims.

The gyroscope to the left was intended to provide a fixed directional reference; by following its directional indication, an operator set course changes manually.

Patent 1,111 applied for 15 January 1910, complete specification (with figures) left 12 August 1910.

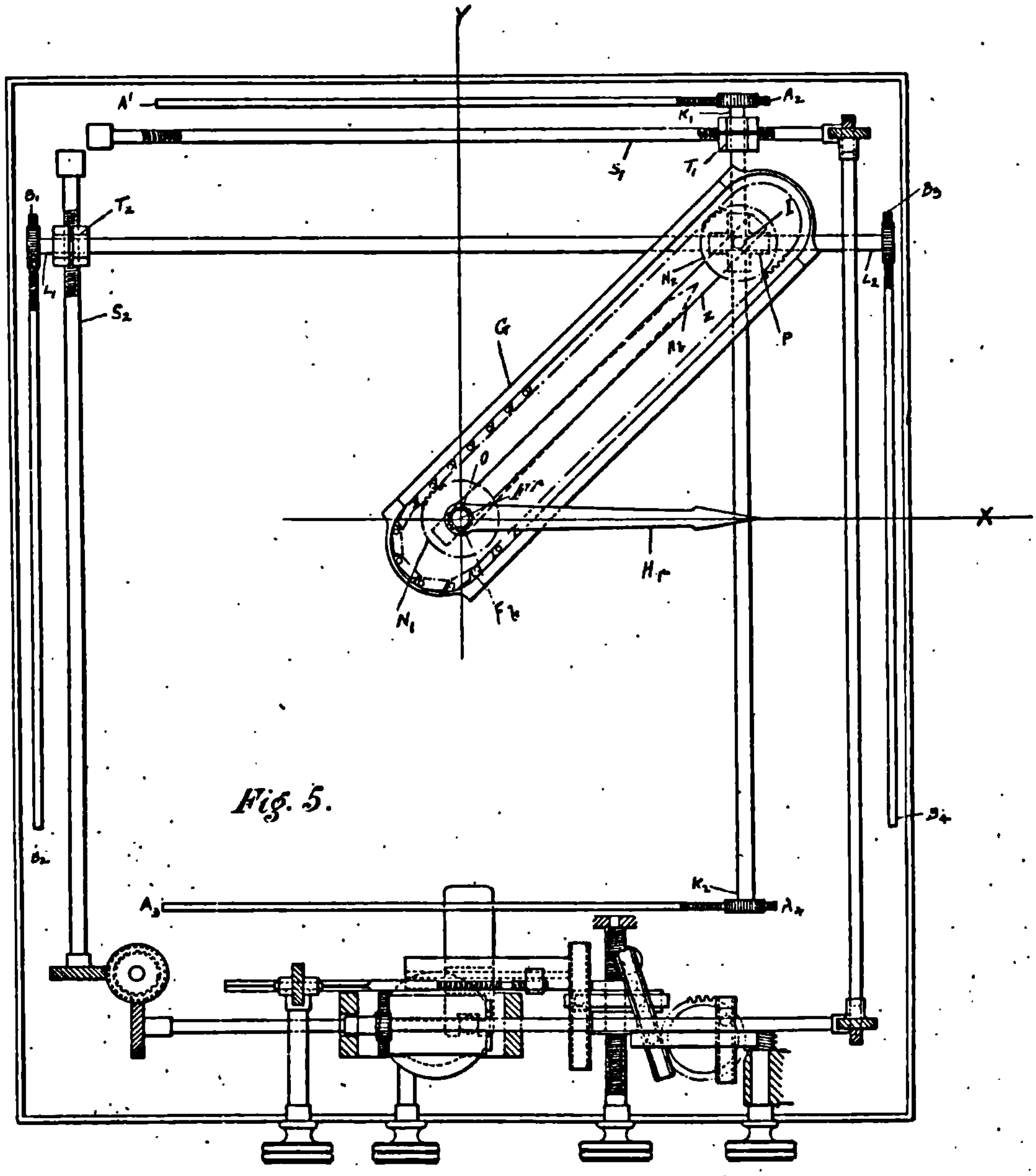


Fig. 2.

15. Argo Clock Mark I

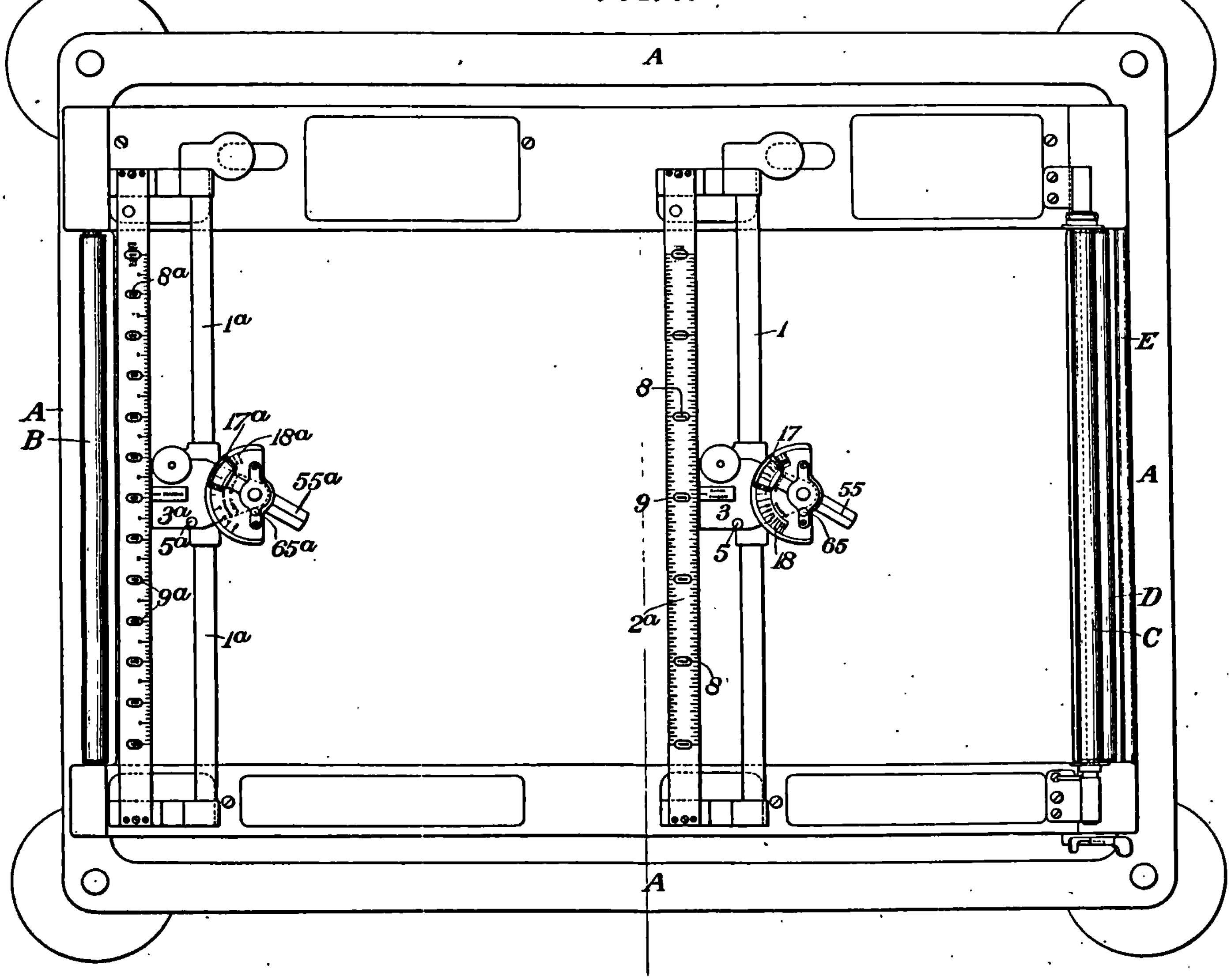
The fixed central pivot of the range hand represented own ship, while the motion of the cross-piece P relative to the centre simulated the target's virtual course.

The rotation of the horizontal screw S_1 moved P horizontally at a speed proportional to the component of virtual speed parallel to own course; likewise, the vertical screw S_2 moved P in proportion to the perpendicular component of virtual speed.

The screws were driven by two variable-speed drives; the disc and ball of the upper drive can be seen at the bottom of the diagram. The balls were positioned by linkages which generated displacements proportional to these two components when set with own and enemy speed and the angle between courses (Note XII-5).

Patent 360 of 1911, applied for 5 January, complete specification 28 June 1911.

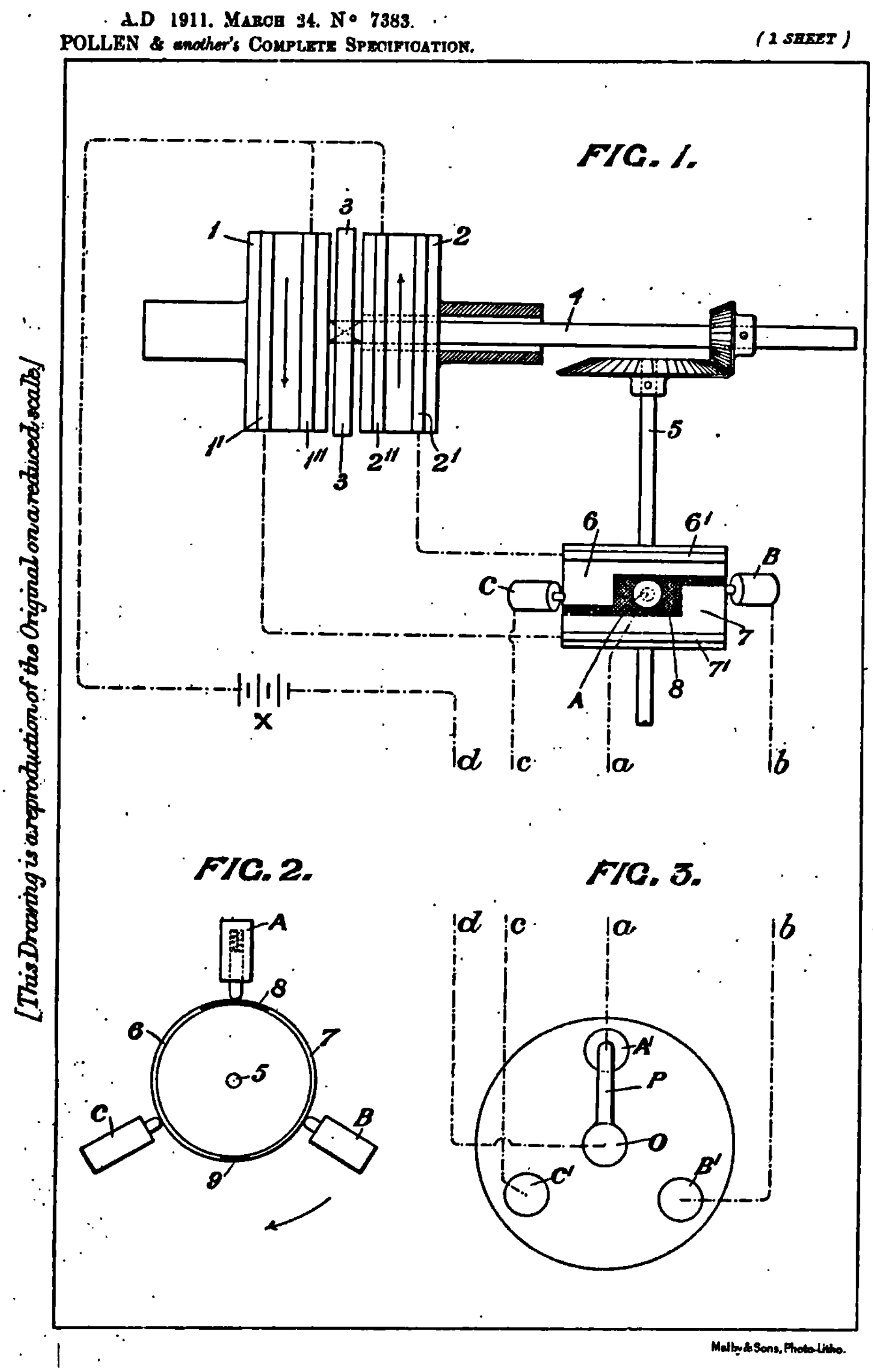
FIG. 4.



16. Argo Rate Plotter

The ranges and bearings transmitted from the rangefinder mounting were plotted in tandem on the one broad strip of paper moving at a constant speed. The range plot was to the right, the total travel of the plotting pen representing a change in range of 6,000 yards. By changing the figures visible through the windows in the scale, ranges to a maximum of 10-16,000 yards (or greater) could be provided. Similarly, the span of the bearing scale was 120°.
The range and bearing rates were measured with the radial lines engraved on the celluloid strips pivoted about the plotting pencils.

Patent 23,351 of 1912, applied for 12 October, complete specification 13 May 1913.



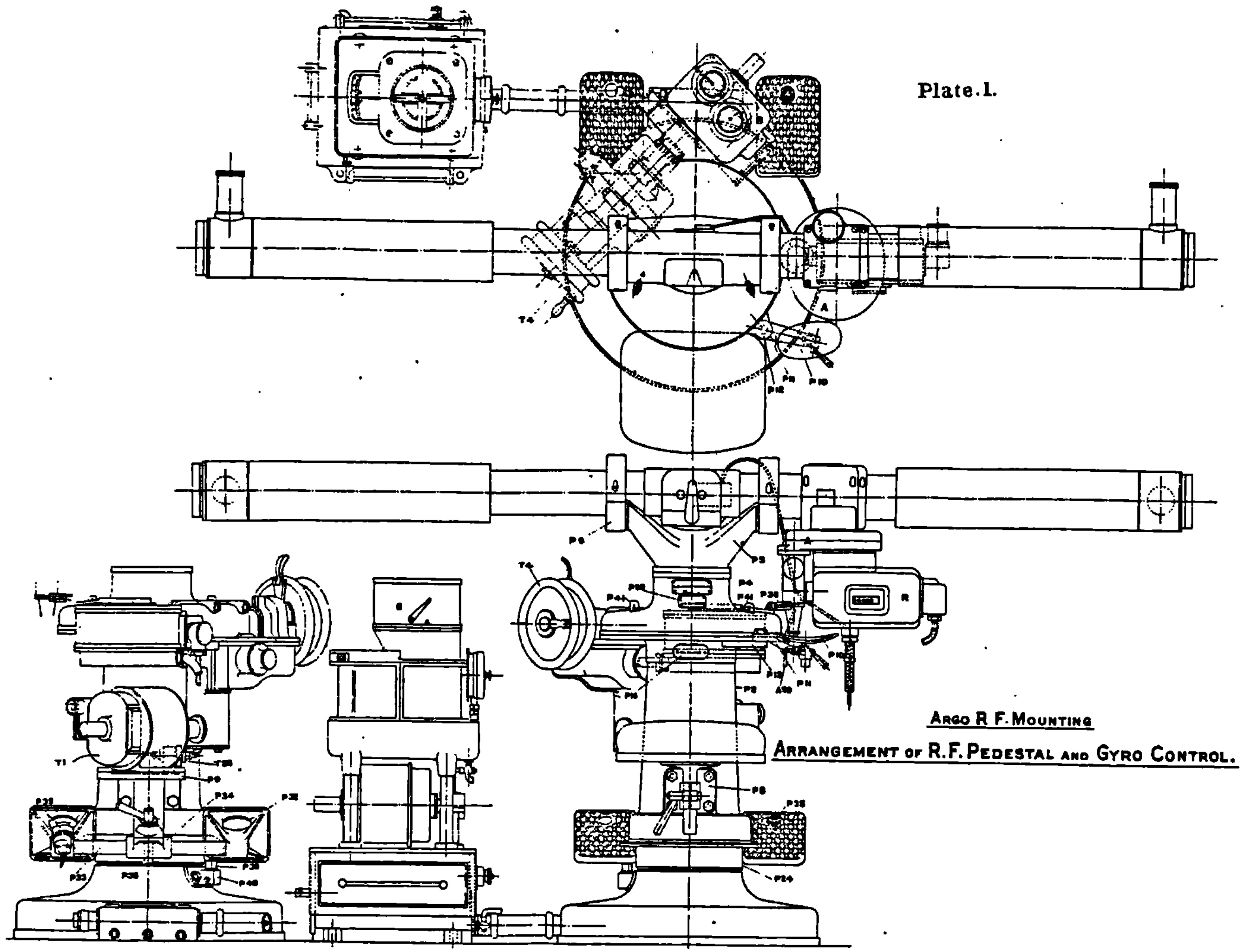
17. Argo Step-by-step Transmission

Fig. 3 shows the simple transmitter; only one stud contact could be energised at a time.

Fig. 2 is a plan view of the receiver drum and the three spring contacts wired to the transmitter. The drum and contacts are also shown in Fig. 1, together with the clutch plate and the pair of continuously-driven, counter-rotating electromagnetic clutches. On the drum, light areas are conducting, dark are insulating.

If the larger insulating gap on the drum lay under the spring contact energised by the transmitter, neither clutch was energised and the receiver was in step with the transmitter. If the energised receiver contact was touching a conducting area on the drum, power was applied to one of the clutches; this would rotate the receiver in the appropriate direction to realign the receiver with the transmitter.

Patent 7,383 of 1911, applied for 24 March, complete specification 25 September 1911.

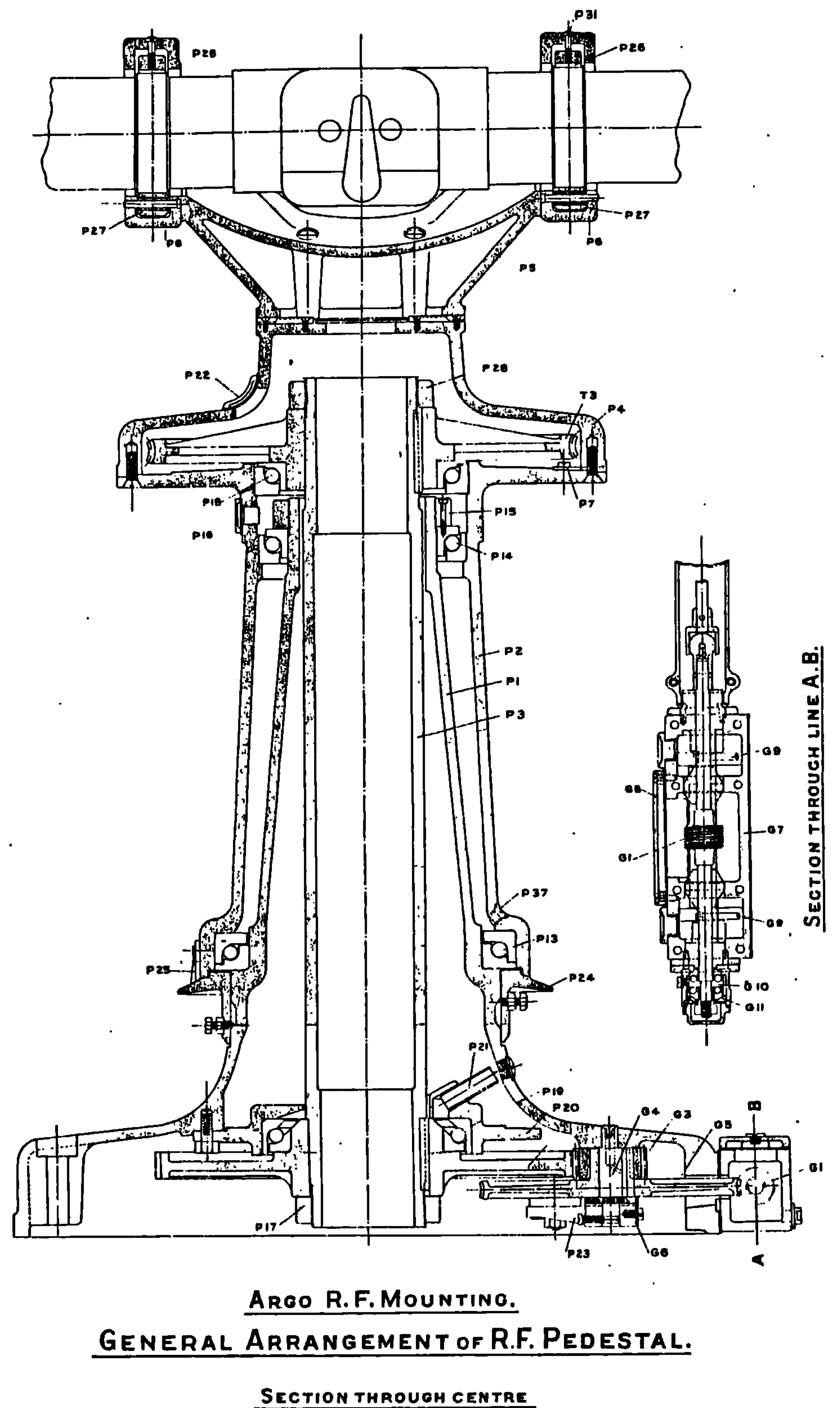


18. Argo Rangefinder Mounting and Air-driven Gyro Control

The rangefinder and the whole upper part of the mounting, which carried the operator's seat, was stabilised by the gyro control to the left of the mounting itself. The air-driven gyroscope can be seen in the top view, which also shows the limited deviation allowed from the initial setting when the gyro was set parallel to the keel.

The power training control is on the operator's left hand. He used his right hand to elevate the rangefinder and to adjust the 'cut'. The range transmitter included cam gear so that, at all ranges, the same rotation of the transmitter corresponded to the same change in range.

Dreyer and Usborne, *Pollen Aim Corrector System, Part I: Technical History and Technical Comparison with Commander F C Dreyer's Fire Control System*, February 1913, Plate I, AL.



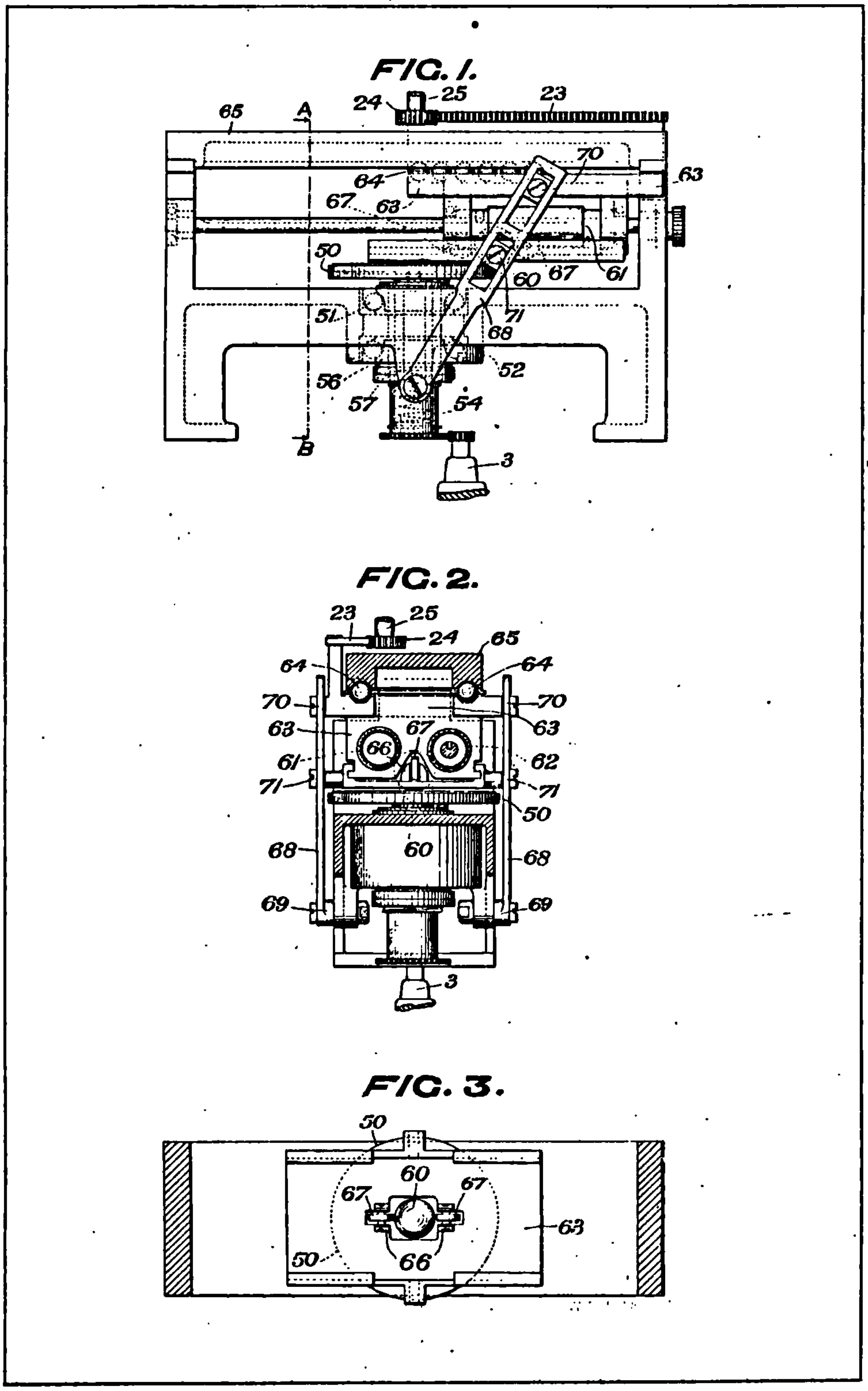
19. Argo Rangefinder Mounting: Section

The mounting comprised three tubes. The middle tube was fixed to the deck. The inner tube was stabilised by the gyro control so that it remained fixed in space, even as the ship yawed. The upper, outer tube carried the rangefinder and operator. By means of the power training, the operator endeavoured rotated this tube at a speed proportional to the rate of change of target compass bearing.

Dreyer and Usborne, *Pollen Aim Corrector System, Part I: Technical History and Technical Comparison with Commander F C Dreyer's Fire Control System*, February 1913, Plate II, AL.

A.D 1912. April 4. No 17,441.
POLLEN & another's Complete Specification. (1 SHEET)

[This Drawing is a reproduction of the Original on a reduced scale]



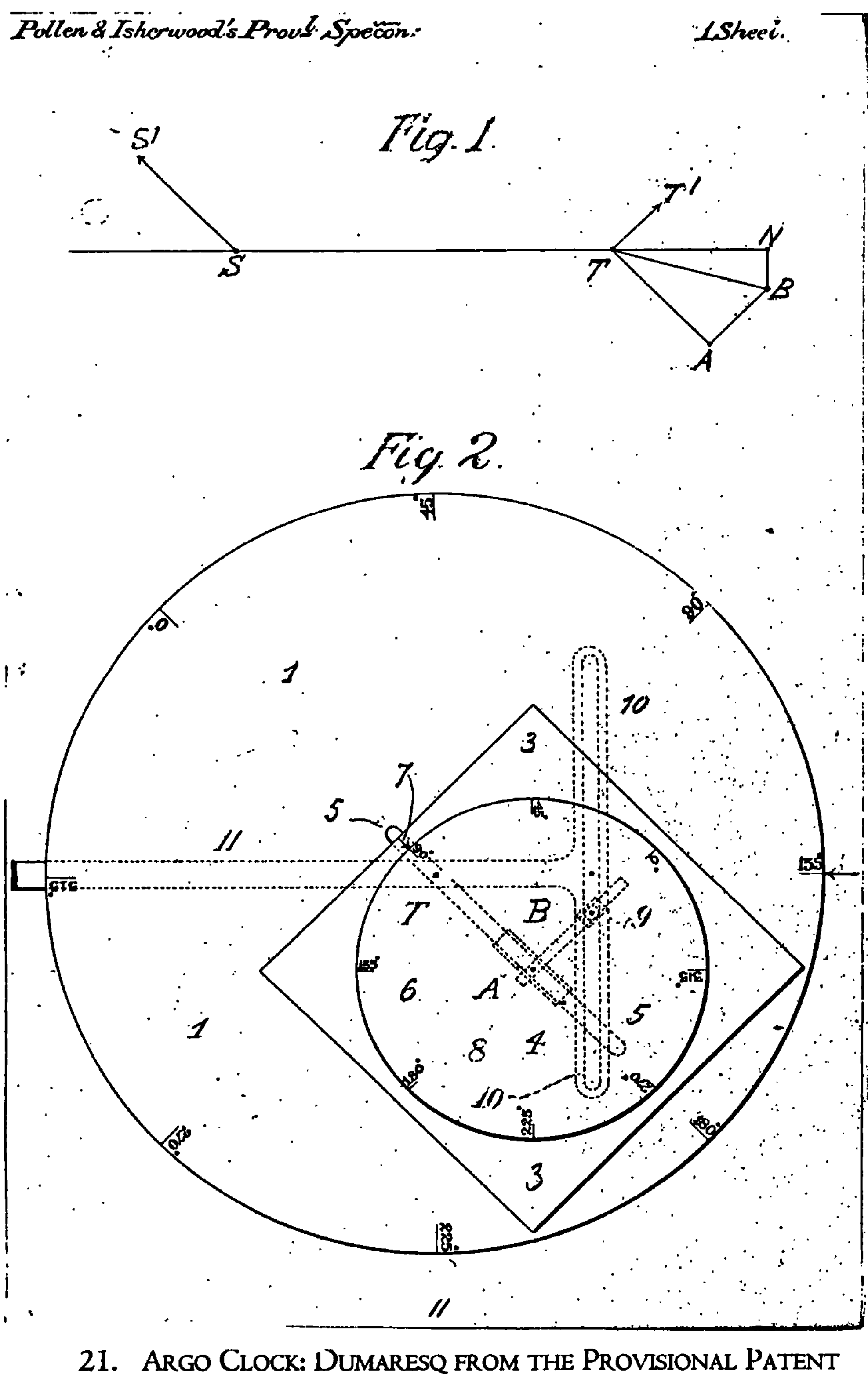
Malby & Sons, Photo-Litho.

20. Argo Variable Speed Drive

The ball is located between the disc and the two rollers in the carriage. The carriage slides on ball bearings. One of the rollers engages with the output shaft.

The side lever controls the position of the plate carrying the small control wheels; the arrangement ensures that the ball is always correctly positioned relative to the rollers. The small control wheels allow the ball to rotate about any horizontal axis without appreciable friction.

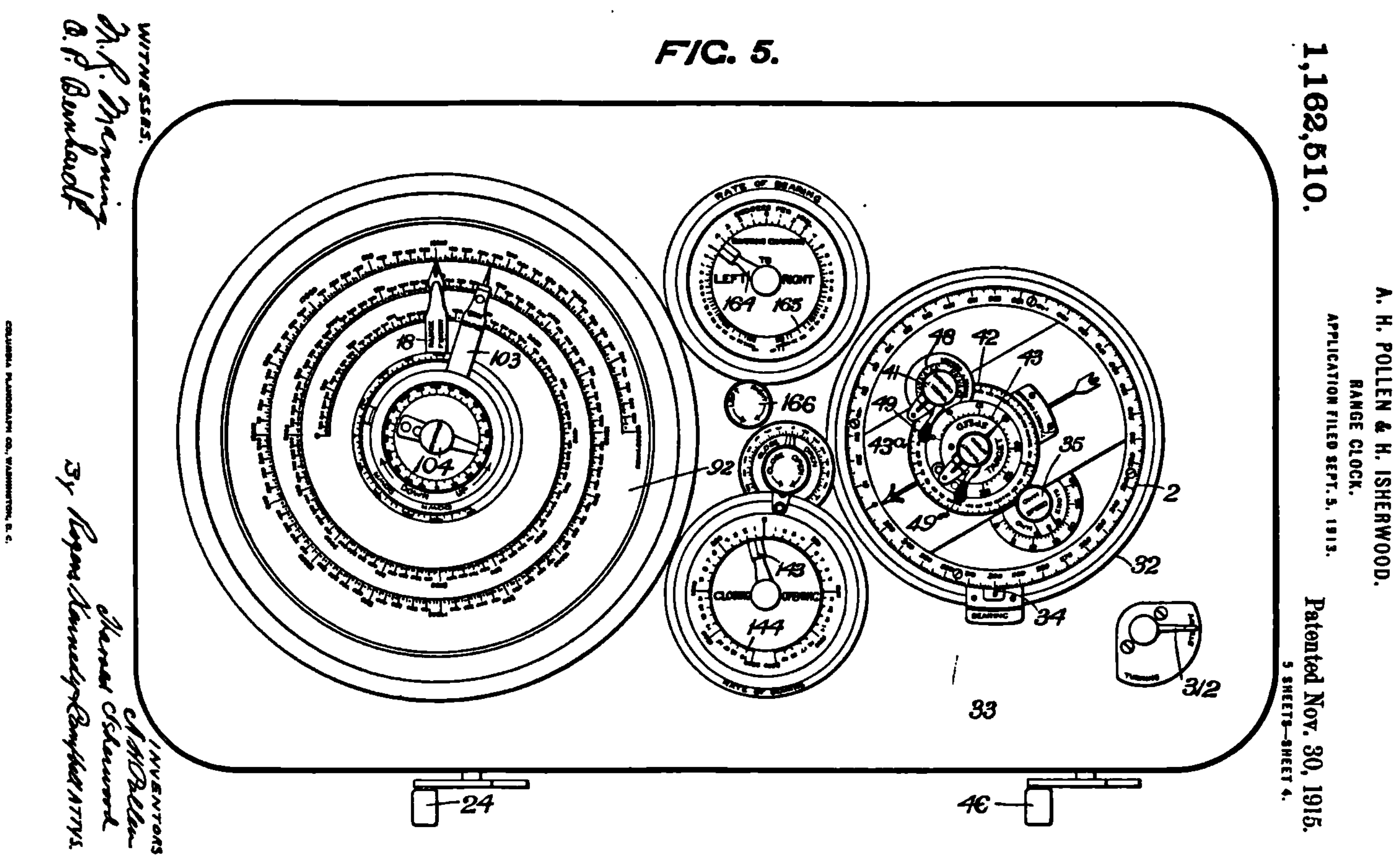
Patent 17,441 of 1912, applied for with complete specification 4 April.



21. ARGO CLOCK: DUMARESQ FROM THE PROVISIONAL PATENT

SS′ and TT′ are courses of own and enemy ship, respectively.
Own speed reversed is represented by the displacement of the sliding piece in the slot 5, cut in the large bearing dial. This sliding piece carried the pivot on which rotated together the smaller 'target course dial' and the bar 'or equivalent' beneath it.
As set, the angle between courses is 90°.
The distance from the pivot A of the pin B sliding on this bar was proportional to enemy speed. Pin B engaged with the T-shaped slide which was coupled directly to the carriage of the variable-speed drive; thus the range-rate was set directly and automatically from the dumaresq mechanism.

Patent 19,627/1911, Provisional Specification with application of 4 September.



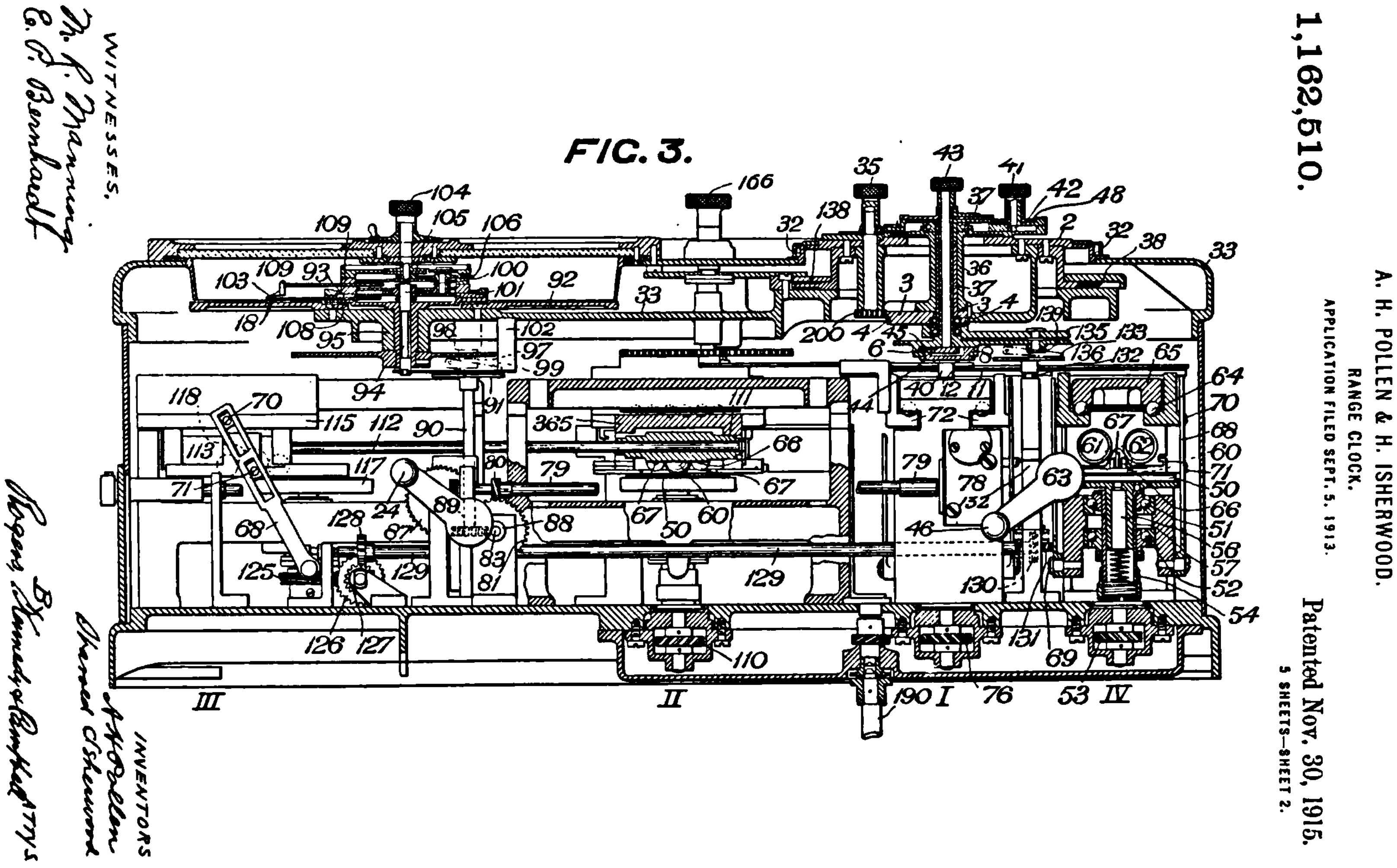
22. ARGO CLOCK MARK III: TOP VIEW

The spiral range dial (reading to 20,000 yards) is to the left. Spotting corrections (the difference between the Range Finder and Gun Range hands) were set using the knob and scales at the centre. The large dial to the right showed the target bearing. The smaller dials displayed the settings of the dumaresq-linkage - own and target speed, target course and target bearing. The STEADY-TURNING lever is at bottom right.

The upper central dial indicated the bearing rate, in degrees per minute, calculated internally from the clock-range and the speed-across from the dumaresq-linkage. The lowest central dial should be labelled 'RATE OF RANGE'. The clock settings for rate could be altered either by changing the enemy speed and course: or by changing the rates using the two knobs and the scale between the two rate dials.

The two handles were used to correct rangefinder-range and target-bearing. Before turning, they were pushed in to disengage the RANGE FINDER hand and BEARING dial from their respective variable-speed drives.

U S Patent 1,162,510 applied for 5 September 1913. The figures are essentially identical to the secret British patent 19,627 of 1911, complete specification 4 April 1912.

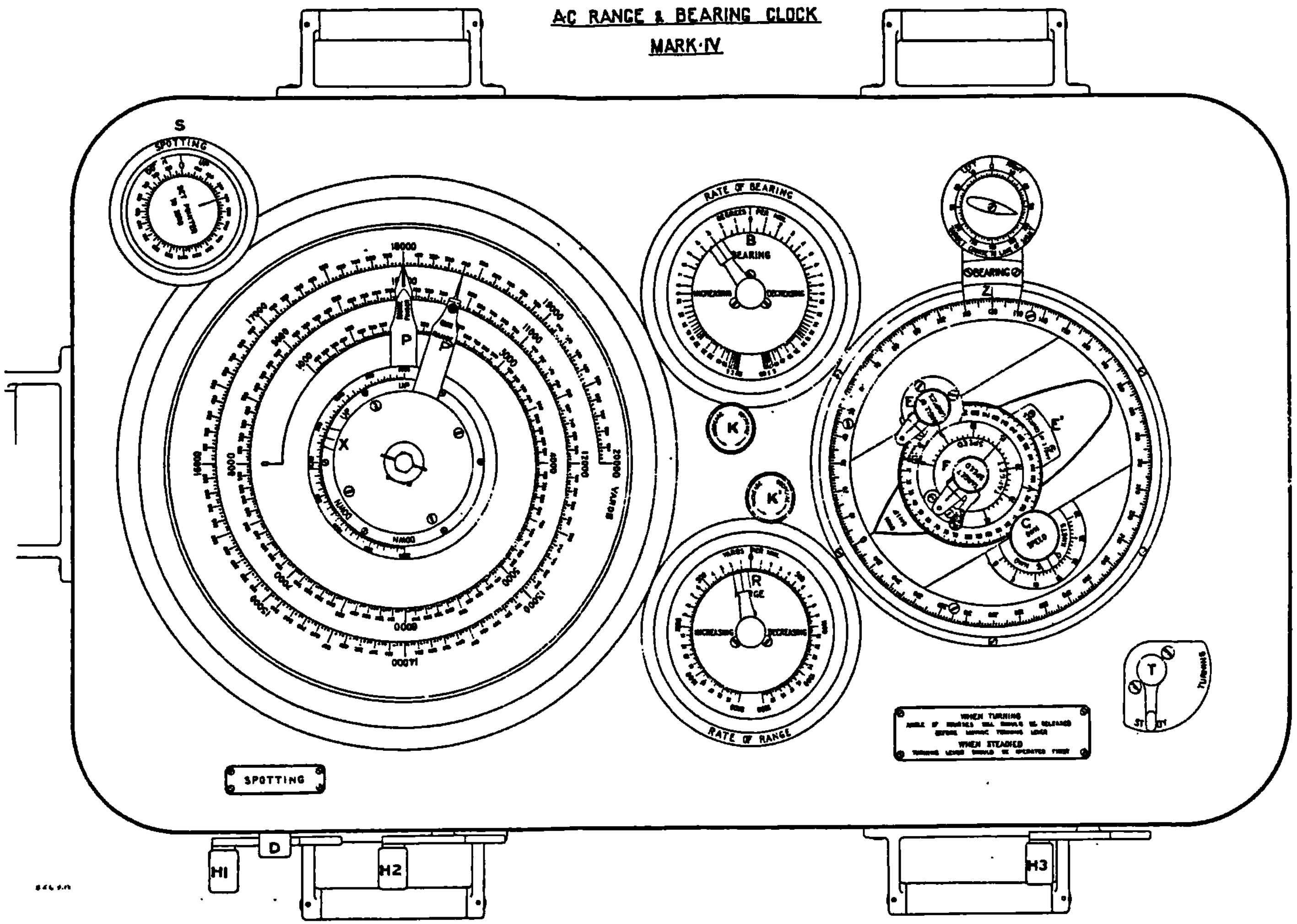


23. ARGO CLOCK MARK III: VERTICAL SECTION

As in Plate 20, the range dial is to the left and the dumaresq to the right. Drive I, which generated range, is directly under the dumaresq, orientated as is Drive IV. This drive was supposed to couple to follow-the-pointer transmitters but it did not register spotting corrections.

Drives II and III (which were orientated at right angles to Drives I and IV) integrated speed-across divided by range to give change of target compass-bearing. Note the shaft (unnumbered) directly coupling the rollers of Drives II and III.

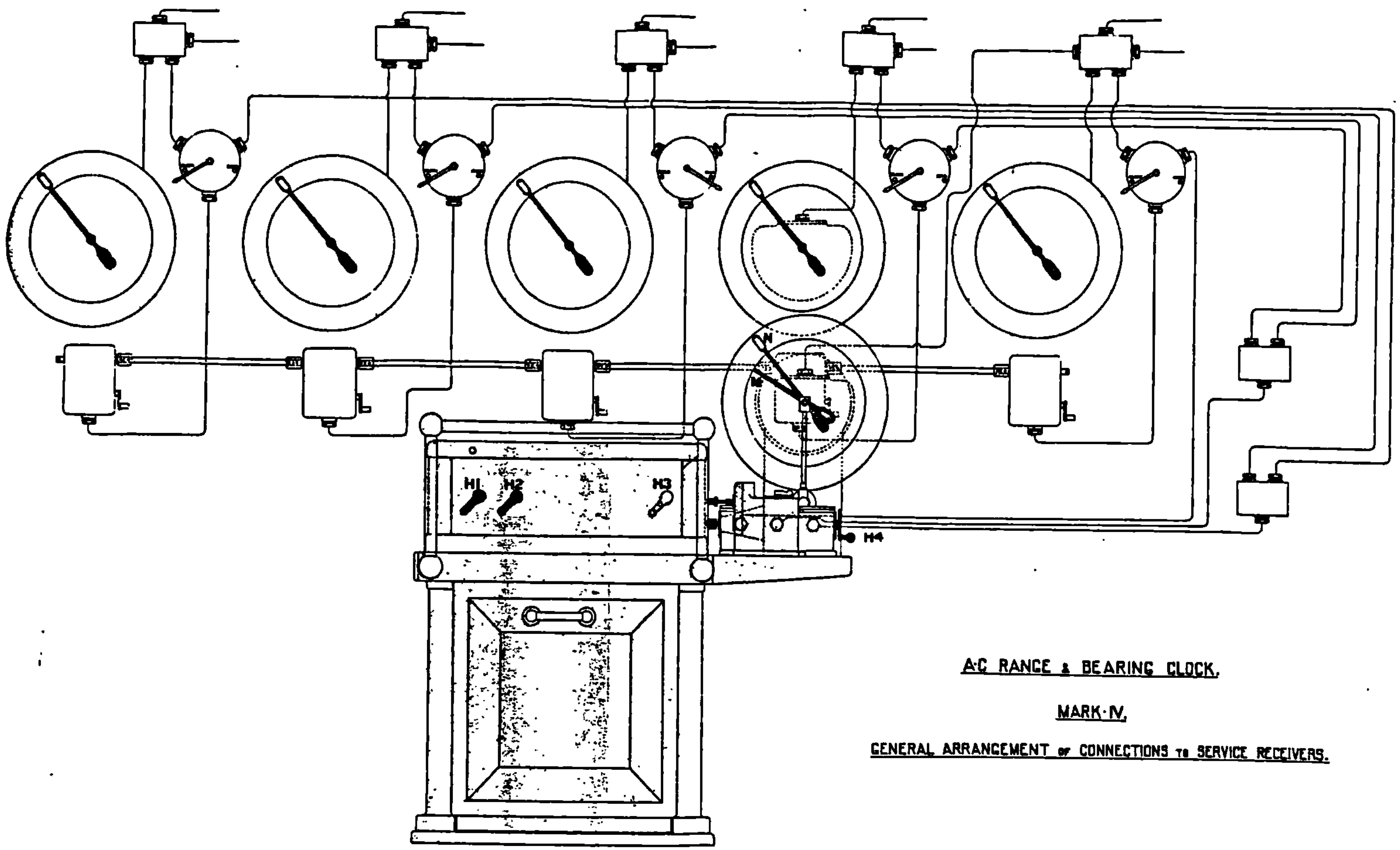
U S Patent 1,162,510 applied for 5 September 1913. The figures are essentially identical to the secret British patent 19,627 of 1911, complete specification 4 April 1912.



24. ARGO CLOCK MARK IV

The latest spotting correction was set on the small SPOTTING dial with the handle H1; the mechanism added this correction to the indicated GUN RANGE and to the total spotting correction shown by the pointer X (near the centre of the range dial). The button D was then pressed to reset the SPOTTING pointer to zero, ready for the next correction.
The clock now had a small dial indicating TARGET COURSE TO LINE OF SIGHT (inclination)
Note the instruction plate giving the procedure to follow when altering course.

Gunnery Branch, *The Argo Range and Bearing Clock Mark IV*, 10 January 1914, Plate II, AL.

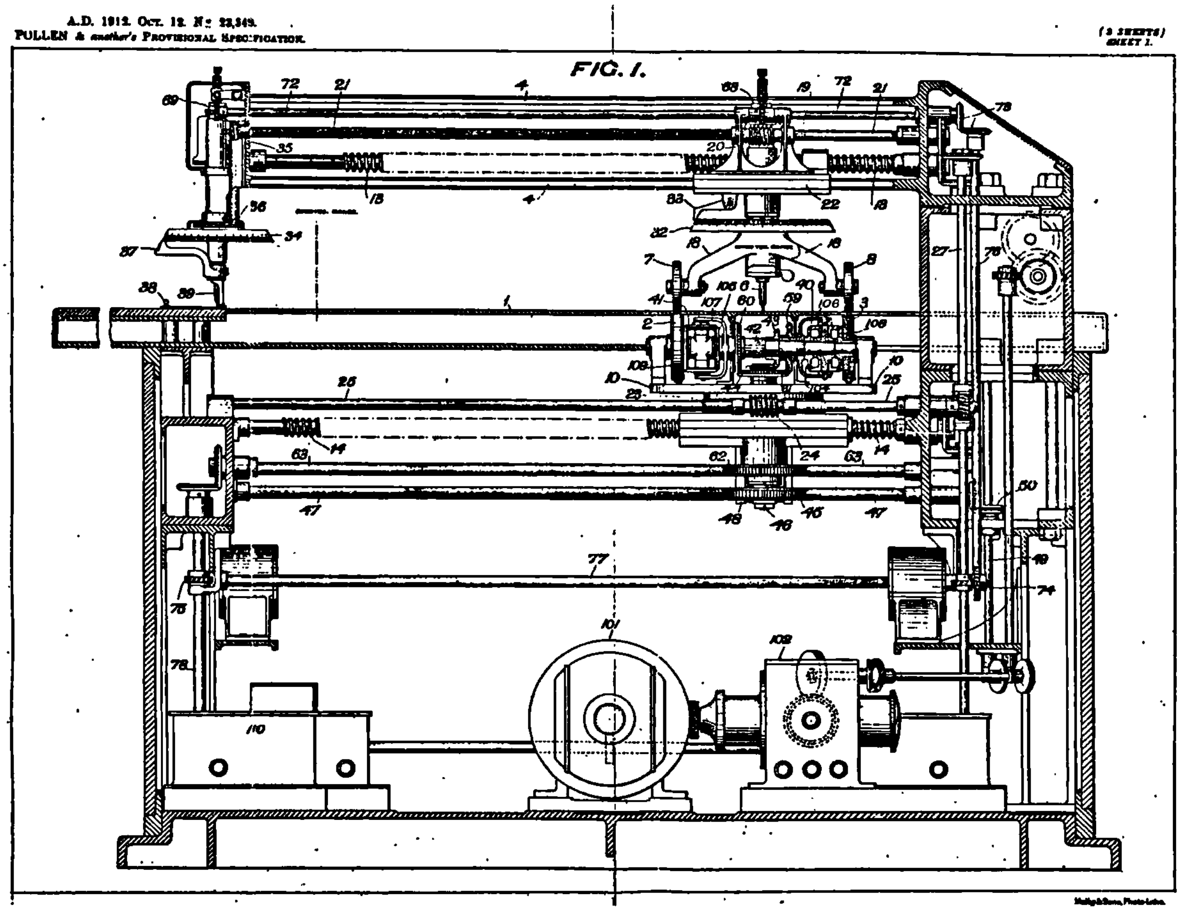


25. Argo Clock Mark IV: Transmitters and Receivers

Handle H1 set spotting corrections. H2 was used to correct the indications of the RANGE FINDER hand; the same change of range was registered by the GUN RANGE hand.

Any changes to gun-range were reproduced by the M pointer on the follow-the-pointer receiver dial mounted on the extension to the right of the clock. The N pointer showed the range being transmitted to the guns; to transmit any spotting correction or correction to clock (rangefinder) range, the handle H4 was used to realign N with M.

Gunnery Branch, *The Argo Range and Bearing Clock Mark IV*, 10 January 1914, Plate XIII, AL.



26. ARGO TRUE COURSE PLOTTER MARK IV: CROSS SECTION

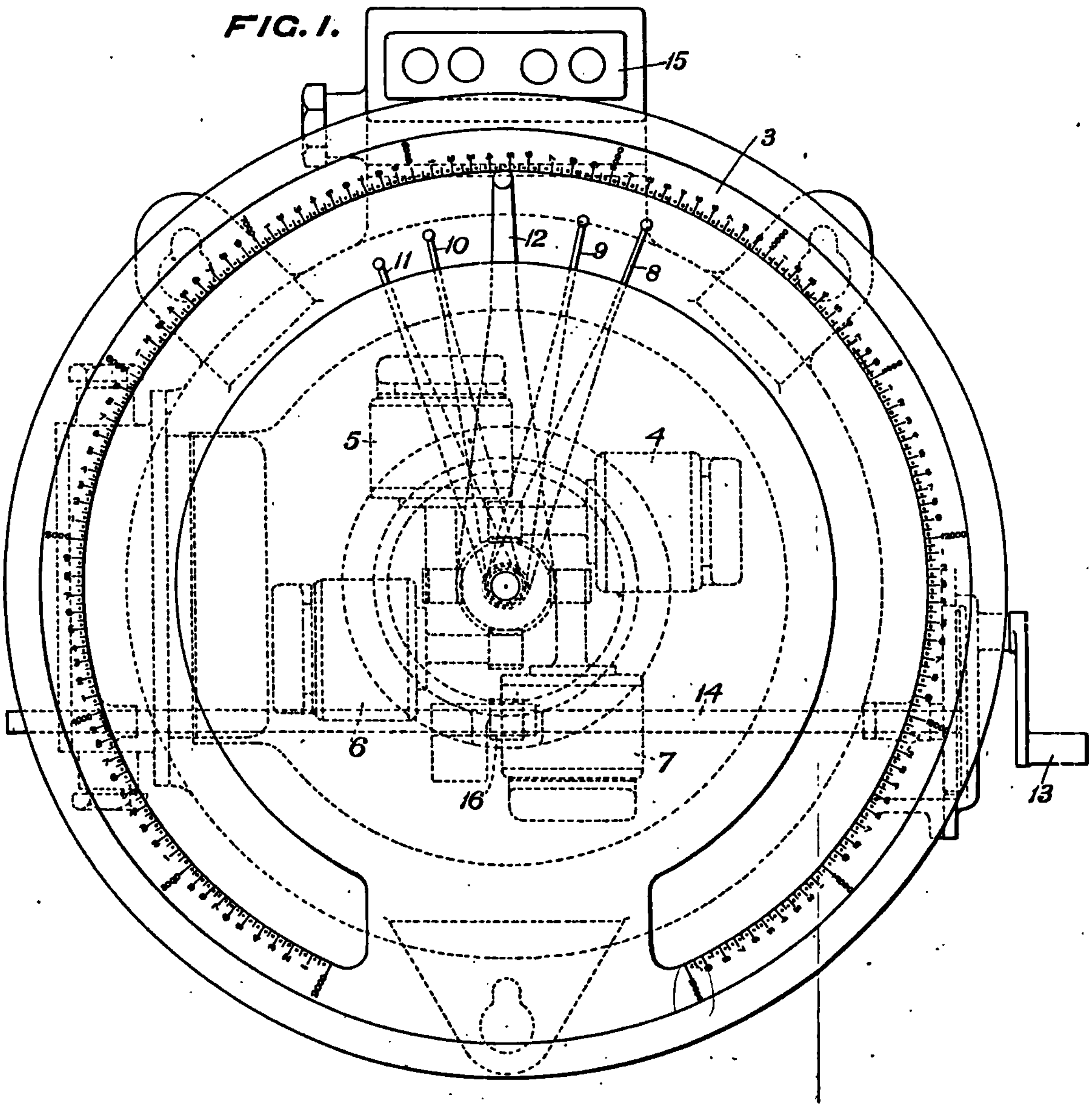
The fixed left-hand pencil marked a point on the chart each time the rangetaker obtained a 'cut'. The chart was gripped between the wheels of the upper and lower carriages to the right; the pencil tracing own course was in the upper carriage. Both carriages always moved together. Their lateral movement altered the distance between the pencils, which was proportional to the range received from the rangefinder. They also rotated together by an amount equal to the change in own compass course (from a gyro compass relay).

The differentials in the lower carriage generated and added two components of rotation. The first caused the wheels to rotate in the same direction, at a speed proportional to own ship's speed (from the Forbes log). The second caused the wheels to rotate in opposite directions, thereby rotating the chart by an amount equal to the change in target bearing relative to the keel, as received from the rangefinder mounting (in steps of ¼°).

Both pencils also drew small circles at minute intervals.

Patent 23,349 of 1912, applied for 12 October, complete specification (with Fig. 4 showing additional differentials) 11 April 1913.

FIG. 1.



27. ARGO AVERAGING RANGE INDICATOR.

The ranges received from up to four rangefinders were indicated by the four smaller coloured pointers. The four coloured lights above the dial showed which pointers were indicating valid ranges.

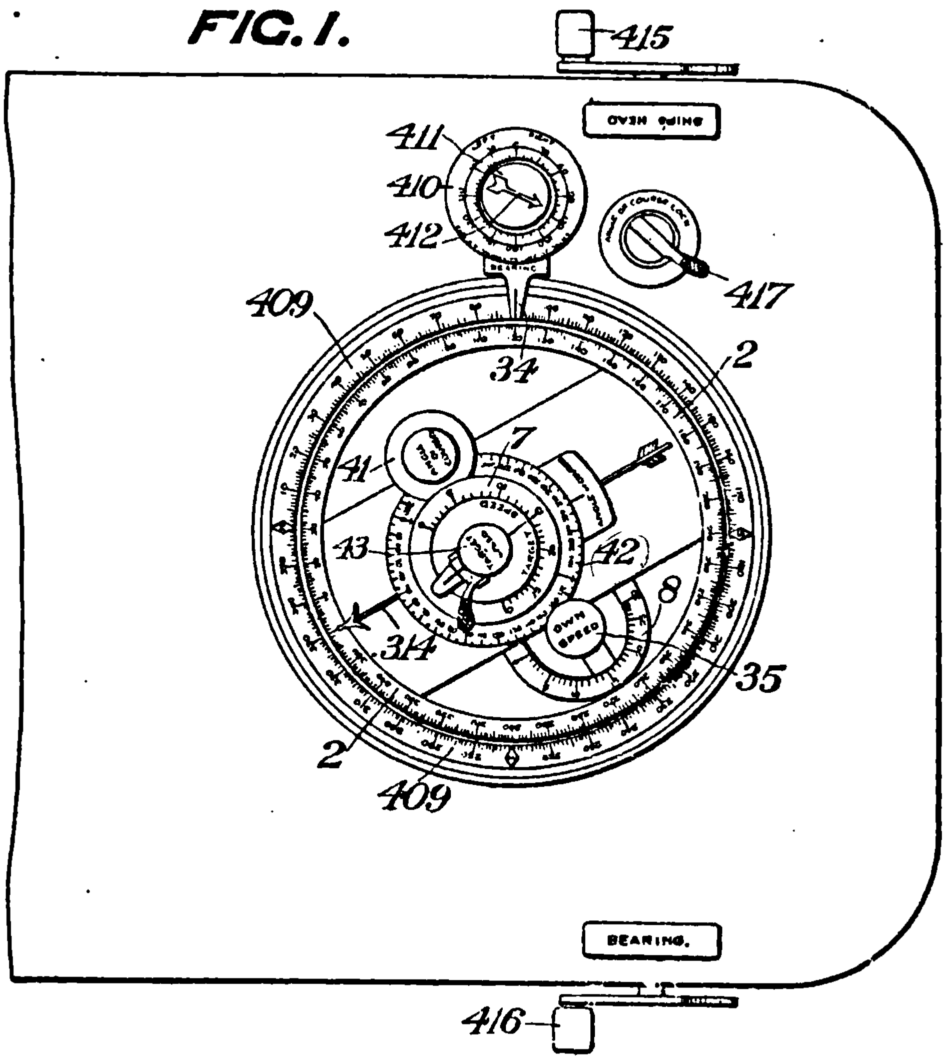
The operator had, by eye, to keep the large pointer (coupled to the side handle and a range transmitter) in the mean of the valid ranges.

Patent 25,768 of 1912, applied for 9 November, complete specification 8 May 1913.

A.D. 1913. MAY 9. N.º 11,009.
POLLEN & *another's* COMPLETE SPECIFICATION.

SHEET 1.

FIG. 1.



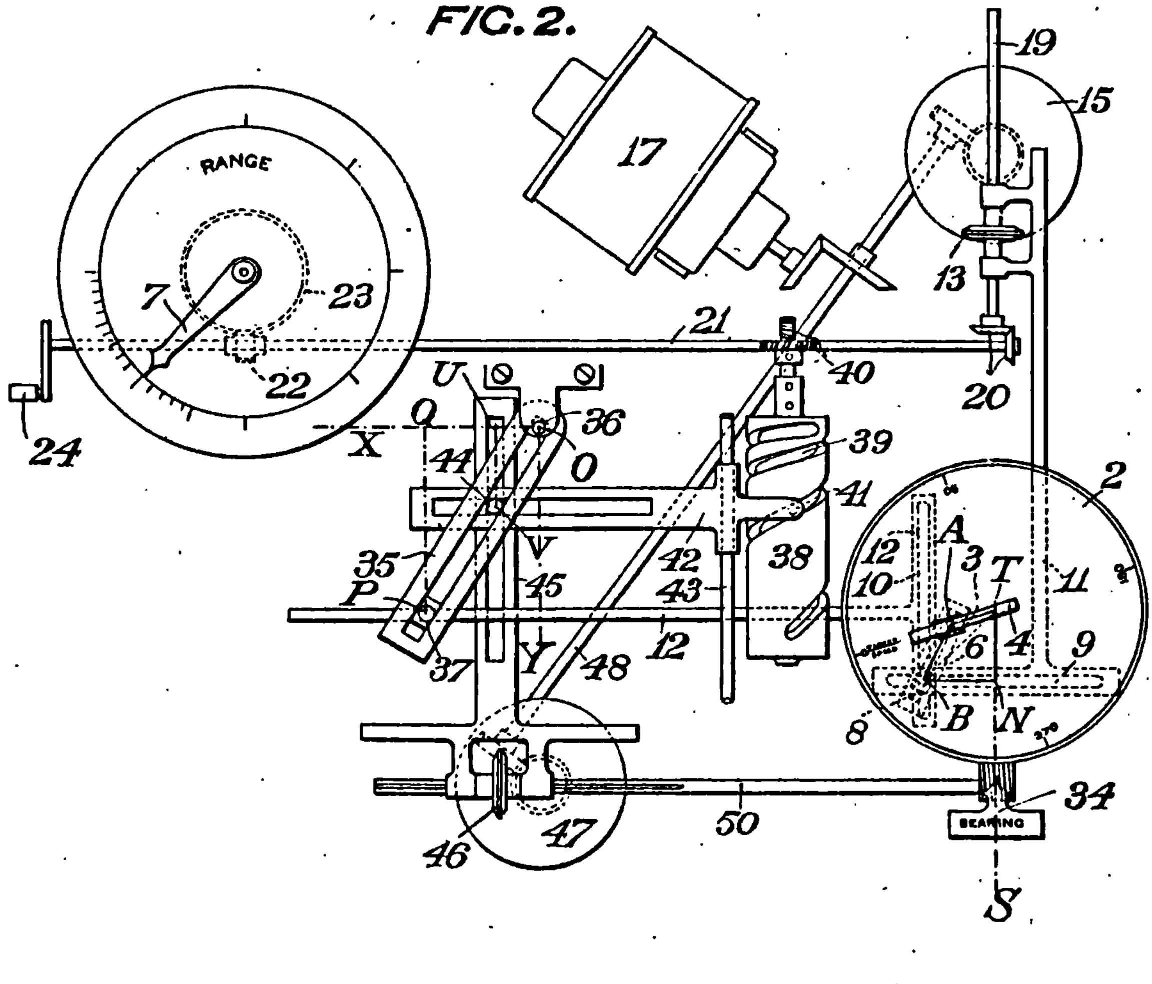
28. ARGO CLOCK MARK V: THE DUMARESQ

The principal new feature is the compass ring around the dumaresq dial. The bearing pointer (now located between the inclination and dumaresq dials) indicated target bearing on the scale around the circumference of the dumaresq dial: and target compass bearing on the compass ring. The large arrow indicated own compass course on the compass ring.

An additional handle (415) was used to set or correct own course. The lever for locking the angle between courses has been moved from the dial to the top plate of the clock.

Patent 11,009 of 1913, applied for 9 May, complete specification 8 December 1913.

FIG. 2.



29. ARGO CLOCK MARK V: SCHEMATIC FOR CHANGE OF BEARING MECHANISM

Both variable-speed drives are drawn as though of the conventional disc-and-roller type.
The upper drive, which integrates range-rate, determines the position of the spiral cam, which is cut to generate the reciprocal of range. The pair of linkages multiply speed-across (from the dumaresq) by the reciprocal of range to give the bearing-rate set on the second variable-speed drive. Thus its output shaft of this drive is coupled directly to the bearing dials of the dumaresq.

Patent 16,373/1913, applied for (with figures) 16 July. Complete specification (essentially identical) 16 January 1914.

5

THE DREYER TABLES

While Pollen always remained an outsider, Lieutenant Frederic Dreyer soon gained a reputation as a promising member of the Royal Navy's gunnery elite.[1] Following his 1903 appointment as *Exmouth's* Gunnery Lieutenant, his ship recommissioned as the flagship of the Channel Fleet and Dreyer quickly became a valued adviser on gunnery matters to Vice-Admiral Sir Arthur Wilson.[2] He represented the C.-in-C. on the Calibration Committee chaired by Percy Scott (Captain Edward Harding was also a member)[3] and, in May 1905, first met Arthur Pollen, who had been invited to witness the Bantry Bay trials, and gave Dreyer a copy of *Fire Control and Long Range Firing*. The two met again in the spring of 1906, when Pollen presented plans of his system to a group of naval officers, after which he was given a tour of *Exmouth*.[4] On 31 October 1906, he sent Dreyer a copy of the *Jupiter Letters* with a request for 'any reflections you may have'. The latter replied, apologising for the delay, on 15 December,

> ...but as regards giving you an opinion, as I have never seen your gear and do not know how you have actually overcome the many great mechanical difficulties...I must put that off until I have the pleasure of again seeing you.[5]

[1] Dreyer came first (of three) in the demanding Advanced Course at Greenwich: examination certificates in DRYR 1/2, CC. For his early career and inventions, see Appendix XVII.
[2] Frederic Dreyer, *The Sea Heritage* (London, 1955) pp.32, 45, 47-8, 52-3 and 57.
[3] *Report of the Committee on Calibration*, August 1905 in 'Calibration of Guns. Report of Committee, &c' in ADM 1/7835, PRO.
[4] Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) p.122.
[5] Pollen to Dreyer 31 October and Dreyer to Pollen 15 December 1906 in RCAI Claim Files, T.173/91 Part VII, PRO.

In his memoirs, Dreyer claimed that the eponymous tables originated in a proposal that he put forward on 10 December: which as Sumida points out, was just before the belated reply to Pollen.[6]

> In December 1906 I submitted a memorandum...to Sir Arthur Wilson in which I proposed a chronograph of range-finder ranges....He forwarded this to the Admiralty. I expanded this later into a complete fire-control table.[7]

In fact, the device was originally called a 'Rate of Change Calculator' and it was designed to obtain range rates directly from a series of ranges.[8] As can be seen from Plate 30, the device was in no sense a chronograph i.e. a means of plotting ranges against time:[9] nor, as Dreyer and Usborne claimed in 1913, could it provide 'the mean range and rate of change of range'.[10] It was merely a rate calculator which, within the existing system, provided a non-too-convenient means for obtaining momentary rates from successive pairs of ranges.[11] It was 'never used in the Service at all'[12] and Sumida must be correct in concluding that 'the Ordnance Department dismissed Dreyer's design as unworthy of serious consideration'.[13]

ASSISTANT TO THE DNO

By the close of 1906, it was already agreed that Dreyer's next posting would be as an assistant to the DNO, Jellicoe. However, on leaving the *Exmouth* on 7 January 1907, he was first given a temporary appointment as gunnery adviser on the Experiment Cruise of HMS *Dreadnought*.[14] In his report, Captain Bacon called 'their Lordships' attention to the great assistance rendered me by Lieutenant Dreyer, whose theoretical and practical gunnery knowledge has been of very great value in carrying out the gunnery practices'.[15]

[6] *IDNS* (*op. cit.*) p.122.
[7] *Sea Heritage* (*op. cit.*) p.55.
[8] Dreyer, 'Change of Range', 10 December 1906 in DRYR 2/1 and T.173/91 Part III.
[9] The term was first used in 'Remarks on Local Turret Control by Commander F.C. Dreyer R.N....', 5 September 1910 in 'Local Control of Turret Guns. Special Firing carried out by HMS 'Vanguard'...' in ADM 1/8147.
[10] Commanders F C Dreyer and C V Usborne, *Pollen Aim Corrector System Part I. Technical History and Technical Comparison with Commander F.C. Dreyer's Fire Control System*, Gunnery Branch 1913, p.5 in P.1024, AL.
[11] 'It was a crude instrument, I confess....it was not actually a graph'. Dreyer's evidence in RCAI Minutes of Proceedings, T.173/547 Part 16, p.13.
[12] Captain Tower before RCAI, T.173/547 Part 11, p.7.
[13] *IDNS*, p.122.
[14] Jellicoe to Dreyer, 11 December 1906 in DRYR 3/2.
[15] Captain R H Bacon, *Report on Experimental Cruise*, 16 March 1907, p.5, ADM 116/1059.

On Dreyer's return in April to join the Ordnance Department, Jellicoe made him responsible for:

1. Non-transferable mountings except electrical
2. Sighting gear, rangefinders (except experimental)
3. Communications, including fire control....

When Bacon replaced Jellicoe as DNO in August, Captain Edward Harding was still responsible for 'rangefinder experiments', including Pollen's Aim Corrector System.[16] Both Harding and Dreyer were in the party which visited the Linotype works on 11 June 1907:[17] but, shortly after taking up his new post, Bacon ended Harding's direct involvement with the A.C. system,[18] which gave Dreyer full responsibility for the forthcoming trials in *Ariadne*. Given his high opinion of Dreyer, Bacon probably saw no reason to deny him full responsibility for rangefinders and mountings; also, the new DNO may well have distrusted Harding's long and close association with Pollen and believed that Dreyer would evaluate the A.C. gear more objectively.

Dreyer's new post gave him the opportunity to submit new inventions directly to the DNO. In June 1907, he put forward two proposals written jointly with his elder brother Captain J T Dreyer, RA. John Dreyer was well known as an inventor of gunnery devices; in his reports to his successor, Jellicoe mentioned a range clock (though 'backlash in the gearing has so far delayed the trial'), a sight embodying a number of range corrections and a calculator for determining the difference between true and gun range.[19] The first of the Dreyers' new proposals was called, rather confusingly, a 'Position Finder for determining Rate of Change of Range'. It is important as the first description of what would later be called a time-and-range plot (Plate 31). However, Pollen's influence is apparent in the idea of controlling the plotting pencil from the rangefinder, and in the acceptance that the scheme must be able to cope with a rapidly changing range-rate. Frederic Dreyer wrote:

[16] *Sea Heritage* pp.56-7. *Paper prepared by the Director of Naval Ordnance and Torpedoes for the information of his Successor*, July 1907, pp.27 and 49, AL. The 'Aim Corrector System' is mentioned in the section headed 'Rangefinders'.

[17] *IDNS*, pp.121 and 123. Pollen before RCAI, T.173/547 Part 14, p.82.

[18] Harding before RCAI, T.173/547 Part 3, p.34. Harding remained in the DNO's department until 11 December 1908: service record, ADM 196/62, p.355.

[19] *DNO for Successor*, July 1907 (*op. cit.*) pp.20, 22 and 23. The last two were subsequently adopted and remained in service for many years: Admiralty, Gunnery Branch, 'Pamphlet on the Mark III* Dreyer Table 1930', Plate 1 in 'Guard Book for Pamphlets on Dreyer Tables', AL. Admiralty, *The Gunnery Pocket Book 1932 (reprinted 1938)*, pp.60-1.

> ...the impression might be that it would be better...to draw a smooth curve through a number of ranges obtained, the inclination of this curve...giving a measure of the rate of change of range at that point. We are, however, of opinion...that the best method of smoothing the curve is to allow the Range Clock to do so....
> It must be borne in mind that the rate of change of range is a variable which alters from instant to instant, which fact makes the drawing of a smoothed curve through a number of points an extremely difficult method and one of more than doubtful reliability.[20]

In fact, as shown in Appendix XVIII, Note 1 (XVIII-1), a range-clock would not smooth out a fluctuating rate. Thus this fallacious assumption led Dreyer to reject explicitly what was to be an essential feature of the later rate-plotting tables, while this latest invention was left, like its predecessor, with no other purpose than to calculate rates from pairs of ranges.[21]

In his letter to the DNO, Dreyer also stated that: 'Our proposal to use three operators for a 9 ft range Finder is now under trial in the "Excellent" '; the trial was to determine only:

> ...whether two separate layers for elevation and training, and a third man observing and reading off, will not give better results than are at present obtained with one man laying the instrument, observing and marking off.[22]

There was no mention of further adapting the mounting to take bearings. Dreyer requested authorisation for Portsmouth Yard to prepare a fully-engineered conversion kit: and also for Thomas Cooke and Sons (because they manufactured the Land Service Position Finder) to tender for the supply of a 'Rate of Change of range instrument'. In the Autumn, probably in November or December, both the rate instrument and the rangefinder mounting were tried out in the *Revenge* by Lieutenant A T Johnstone of *Excellent*.[23] Perhaps, at some point in this trial, when the rate was only changing slowly, Johnstone found that the rate could be measured directly by aligning the bar with the mean slope of the curve: but, in any event, this first rate instrument was not mentioned again.

Dreyer appears to have had little time to participate in these trials. In July, on Wilson's recommendation, he was chosen by Fisher to visit the nucleus crews of the Home Fleet to check their equipment and advise on training for the forthcoming gunnery tests.

[20] Dreyer to DNO, 2 July 1907 and F C and J T Dreyer, 'Position Finder for determining Rate of Change of Range' in T.173/91 Part III.

[21] A second variant resembled the earlier device in requiring only a narrow strip of paper: see XVIII-1.

[22] *DNO for Successor*, July 1907, p.26

[23] *Technical Comparison* (*op. cit.*) p.5 and Tower before RCAI (*op. cit.*) pp.7-8.

> ...I was on the move all the time, coming back to London for a few days every now and again to inform the D.N.O. what gunnery gear [was] needed.
>
> ....
>
> ...In the end the nucleus crew ships' average for the Battle Practice was better than that of the fully manned Channel Fleet. Fisher was delighted.[24]

Dreyer was probably on one of these visits when:

> ...In September 1907, Dreyer met Pollen while the inventor was on his way to Portsmouth...and Pollen later recalled that Dreyer "told me he hoped it would be his duty to crab me when the time came."
> The selection of Admiral of the Fleet Sir Arthur Knyvet Wilson to umpire the official trials insured that Dreyer's desire to play a major role in the blocking of Pollen would be fulfilled.[25]

The words in quotation marks are taken from the record of the 1925 RCAI hearing, but there is a small but important difference between Pollen's testimony[26] and his letter to Dreyer, of 4 January 1908, on which it was based (both are reproduced in Appendix XIX).

> On the occasion of our last meeting...you warned me that you hoped it would be your job to crab it [the A C apparatus] if you could....
> Personally, I am strongly convinced that, unless the system is crab proof...the Service ought not to go to any exceptional expense to acquire it.[27]

Dreyer's declared intent to 'crab it' (the apparatus) rather than to 'crab me' (Pollen), and Pollen's acceptance that this was his proper role, establishes that Dreyer was using the verb in its colloquial sense of 'To criticize adversely...pull to pieces'.[28] He undoubtedly intended to test Pollen's gear to the limits necessary to establish its fitness for service: but that is not evidence of a preconceived intent to block Pollen by any means.

Once Wilson had been invited to supervise the *Ariadne* trials, Dreyer, who remained the responsible DNO's assistant, acted as his adviser. However, Dreyer's only contribution to the equipment actually used against the A.C. system in the final trial on 15 January 1908 was the improved method of taking ranges (though this had already been simplified by making the rangetaker also responsible for elevating).[29] After the War, Dreyer insisted that:

[24] *Sea Heritage*, pp.58-9.
[25] *IDNS*, pp.121-4.
[26] Pollen before RCAI, T.173/547 Part 14, p.84.
[27] Pollen to Dreyer, 4 January 1908 in DRYR 2/1 and T.173/91 Part III.
[28] *Shorter Oxford Dictionary*.
[29] Admiral of the Fleet Sir A.K. Wilson, 'Rate of Change of Range Experiments' in Admiralty, Gunnery Branch, *Fire Control*, 1908, p.28 in ADM 1/8010 and T.173/91 Part I.

> ...Sir Arthur Wilson...was the deviser of this virtual course and speed scheme....I then pressed him...that, in addition...he would authorise a time and range diagram...[30]

and that:

> I was not allowed to try my "Time and Range" apparatus until the "ARIADNE" trial was complete.[31]

The last claim is clearly confirmed by Wilson's report.

> In the first experiment [on] the 15th January...the "Vengeance" had found it impossible to plot any virtual course owing to the small change in either range or bearing. This had led to a proposal to deal with similar cases in future by plotting the ranges on a time diagram....This I was anxious to try and also the Chetwynd compass.[32]

For bearings:

> ...we simply used a torpedo director, which had a telescope attached to it. They were bearings not corrected by compass at all.[33]

With only uncorrected bearings (relative to ship's-head) available, Wilson was probably fortunate that, despite the flat calm, the almost parallel courses provided an excuse for not attempting a virtual course plot. Since range-rate plotting was not used either, *Vengeance* must have fallen back on the established method of getting a rate, by calculation from timed ranges. Thus the trial with *Ariadne* was even more of a sham than has previously been recognised.[34]

Dreyer's main contribution was made in the experiments conducted by Wilson in *Vengeance* between 17 and 21 January 1908. The aloft rangefinder was fitted with a Chetwynd compass and what Wilson called Dreyer's 'push-pull training gear'. The time-and-range plot was made on simple squared paper, but Wilson, like Pollen and Dreyer before him, was concerned about curvature and insisted:

> The object of this diagram was to give the rate of change when bearing is altering very slowly...when the bearing is altering rapidly, the time diagram would give a very erroneous forecast.

After the experiments, Wilson wrote a detailed report on his virtual course proposals, to which Dreyer's 'Hints on Battle Firing' were appended. In both texts, the preferred method for obtaining the rate from the time-and-range plot was not to draw a simple meaning line; instead, the means of two successive groups of three ranges were to be

[30] Dreyer before RCAI, T.173/547 Part 16, p.22.
[31] Dreyer to Vice Admiral Sir Frederick Field, 12 November 1923 in DRYR 2/1. See also 'Some comparisons between the Argo Clock and the Fire Control table in "Monarch" n.d. but late 1912, T.173/91 Part VII and *Technical Comparison*, p.6.
[32] Wilson, 'Rate Experiments' (*op. cit.*) pp.26-7.
[33] Dreyer before RCAI (*ibid.*).
[34] *cf. IDNS*, p.130 for time-and-range plotting on 15 January.

obtained graphically, after which the rate could be measured as the slope of the line joining the two mean points.[35] The preoccupation with curving rate plots was still apparent.[36]

Apart from the advice that:

> Admiral of the Fleet Sir A. K. Wilson's report and recommendations...should be most carefully studied.

in his 'Hints', Dreyer did not mention virtual course methods, but he took the range rate ideas further. He recommended that, as in the previous year's rate instrument, the plotting paper should be driven by clockwork. Also, he proposed a second plot on which each mean range-rate (obtained from six ranges) should also be plotted against time; he supposed that a changing rate would appear as a smooth curve.[37]

In later years, Dreyer made much of his third proposal, to set the Dumaresq by a cross-cut (not a term then in use) of range-rate and deflection.[38] However, he did not suggest a time-and-bearing plot, but instead that a single bearing rate could be obtained by calculation.

> Take a series of bearings at intervals for a few seconds apart, noting the times, and after a pause of about one minute, take another set of bearings and times.
> Mean each of these sets...and take their difference.

Furthermore, the cross-cut idea is introduced almost as an aside.

> The following method is one of many that can now be employed to keep the Dumaresq properly adjusted.
> Set own speed on the bar as usual.
> Point the sighting vanes at the enemy...
> Then pull out enemy's dummy ship until its stem is at the intersection of the line of... deflection, and the line of the rate of change of the moment.[39]

Thus Dreyer placed much more emphasis on rates than Wilson, which was certainly in accord with Bacon's recommendation to equip the Fleet with time-and-range boards as the first step in the introduction of plotting (Chapter 3).

[35] Wilson, 'Rate Experiments' pp.26 and 46. Dreyer, 'Hints on Battle Firing' p.52 in *Fire Control*, 1908 (*op. cit.*); for Dreyer's authorship, see 'Remarks on Admiralty Counterstatement to Rear-Admiral Dreyer's Claim', n.d. but probably 1925, p.9 in DRYR 2/1.

[36] The actual time-and-range plots made in *Vengeance* on 17 January are in ADM 1/8010. There are examples of slow and rapid change of rate, the 'means-of three' apparently lying close to the underlying hyperbolic curve.

[37] Dreyer, 'Hints' (*op. cit.*) pp.52-3

[38] For example, see *Technical Comparison*, p.10.

[39] Dreyer, 'Hints', pp.50 and 53-4. Another means of keeping the Dumaresq adjusted was a cross-cut of range rate and virtual course (speed not required). Dreyer later claimed that he had tried this in *Vengeance*: 'Some comparisons...', 1912 (*op. cit.*) and *Technical Comparison*, p.6.

While still aboard *Vengeance*, Frederic had written to his brother requesting help with the mechanical details of a range-keeper working on the principle of virtual course;

> ...the reason why that arose in my mind was that I had Sir Arthur Wilson's instructions to make virtual plots.[40]

John's sketches show what is in effect a mechanical realisation of Fig. 2.6, with a traveller propelled at virtual speed by a long screw (Plate 32). This screw was driven by a variable speed drive, for which John Dreyer proposed an arrangement of two cones, one driving the other through a movable belt (Plate 33).[41] Thus even this first Dreyer range-keeper incorporated a variable speed drive, though of a type not found in other fire-control gear. As discussed in XVIII-2, at this time Pollen and Isherwood did not consider variable-speed drives suitable for range clocks; when, a month later, they patented a clock also based on virtual course, a speed proportional to the length of a virtual-speed link was generated using an entirely different principle, that of the inclined plane.[42]

In February 1908, Dreyer also corresponded with Elliott Brothers about his proposal to modify the Dumaresq so that the rate could be kept (approximately) during a turn.[43] At this early date, he was alone in showing a concern for rate keeping while the firing ship manoeuvred (though his virtual-course range-keeper assumed steady courses). Like Pollen, Dreyer was still a long way from realising his final system: but he had at least initial conceptions for rate plotting, range-keeping and even rate-keeping under helm. It must also have been clear to him that Wilson intended, by almost any means, to secure the rejection of the A.C. gear. Thus early 1908, rather than in 1906 during his previous service with Wilson,[44] seems much more likely as the moment when Dreyer first saw clearly that he could be a rival to Pollen with a fire control system of his own.

In August 1908, he and his brother applied jointly for patents (which were sealed as secret) for the three-operator range-finder mounting and for an improved Time and Range apparatus. The latter confirms that Frederic had now accepted that a mean range rate could be obtained by plotting a series of ranges against time and then measuring the rate as the slope of the underlying curve. Thus the plotter was provided with a transparent disc with engraved parallel lines, the disc being rotated until the lines were judged to be

[40] Dreyer before RCAI, T.173/547 Part 17, p.3.
[41] John to Fred. Dreyer, 17 January 1908 with attached figures in T.173/91 Part III.
[42] Patent 2,497 applied for 4 February 1908 p.1 and Fig.6.
[43] Elliott Sales Manager to Dreyer, 7 February 1908 with drawing E.S. 1165, 6 February 1908 in T.173/91 Part III.
[44] *IDNS*, p.121.

parallel to the tangent to the mean range curve; this disc was the principal novelty in what was later considered 'a very important patent'.[45] Although the patent itself has not come to light, the device evidently resembled the 'Time and Range Table (as used in Excellent)' which is illustrated in Hughes-Onslow's essay (Plate 34). This incorporated all of Dreyer's ideas to date on rate plotting, including a motorised paper drive, the circular disc to measure rate and plots of both range and range-rate.[46] Three of the patented plotters were made at Chatham in 1908[47] so, as in 1907, the resources of the dockyards and the experimental section at *Excellent* were used to try out ideas originating in the DNO's department in the Admiralty.

In March 1908, Dreyer returned to normal duties with his reputation further enhanced.[48] In a letter to Julian Corbett, Fisher described him as having 'the brain of a Newton!' although 'only 1 in a 100 could understand him'.[49] Yet he recalled that his situation was an awkward one: though he appears to have forgotten Bacon's insistence that all ships should be equipped first with time-and-range boards.

> The Admiralty in 1908 only accepted my "Time and Range" plotting for use as an adjunct to "Virtual Course and Speed" plotting....Indeed, in 1908 and 1909, as an "ad hoc" officer...in the Naval Ordnance Department...I felt constrained to do everything in my power to develop and promote the official "Virtual Course and Speed" plotting.[50]

In the Spring of 1908, he lectured to officers in training at *Excellent*

> ...in language suited to our indifferent mental capacities, to explain to us benighted "back-enders" the epoch making "Vengeance" method of fire control....in the heckling which followed [Dreyer] refused to discuss Pollen's A.C.[51]

This reception (which was reported to Pollen)[52] seems to reflect the widespread hostility in the Fleet to range-rate plotting. Pollen seized the moment when, in September 1908, he circulated his pamphlet *Reflections on an Error on the Day* to a long list of naval officers. In the later sections, he criticised, justifiably, the conduct of the *Ariadne* trials and argued at

[45] *The Time and Range System, Report of J. Swinburne, F.R.S.*, 5 March 1913, pp.3 and 8, AL (copies of this report and related correspondence provided by Professor Sumida gratefully acknowledged). The patents were 16,463 of 4 August and 16,912 of 11 August 1908, respectively.
[46] 'Fire Control, An Essay by Captain C. Hughes Onslow, RN', Section III, PLLN 1/5, CC. See also 'Notes re Admiralty Letter ...' 9 February 1916, p.1 accompanying G K B Elphinstone to Director of Navy Contracts, 14 February 1916 in 'Fire Control Apparatus, Various Patents', ADM 1/8464/181.
[47] 'Remarks by Commander F.C. Dreyer R.N. on the question of how best to obtain and maintain the gun range in action', 22 July 1910 in, T.173/91 Part III and ADM 1/8147.
[48] During his absences, his work had been looked after by Lieutenant J C W Henley, seconded from *Excellent*: *Sea Heritage*, p.58 and Henley before RCAI, T.173/547 Part 3, p.66.
[49] Fisher to Corbett, 10 March 1908 in *IDNS*, p.135.
[50] Dreyer to Field, 1923 (*op. cit.*).
[51] *IDNS*, p.149.
[52] Pollen before RCAI, T.173/547 Part 14, p.65.

length against manual methods. However, he began the pamphlet with an attack on range rate plotting which, since it refers to a second curve of rate, was clearly aimed directly at Dreyer's 'Hints'.[53]

That Autumn, Captain Constantine Hughes-Onslow wrote to Dreyer requesting information on the latest fire control developments for his War College essay. Dreyer replied directing him to 'the big Fire Control Pamphlet' but also expressing outrage at Pollen's broadcast criticisms.

> The latter has stirred up some agitators to believe his auto-system is best but a searching analysis I think reveals that the simple kitchen table methods are better than the complicated machinery game and produce the same results as the latter only does when in adjustment.
> Mr. P. has just issued a scurrilous pamphlet in which he has evidently been assisted by some "failure".
> ....
> It is a great pity that trusting N.O's [naval officers] <u>will</u> go and discuss "<u>Confidential</u>" matters with <u>any</u> private man and tell him <u>our</u> Secrets.[54]

It is hardly surprising that Dreyer was furious that Pollen was receiving confidential information (including the *Fire Control* pamphlet) and using it to attack Service policy on fire control, for which Dreyer was himself responsible within the NOD. However, his arrogant language so offended Hughes-Onslow that the latter sought Pollen's acquaintance, gave him Dreyer's letter[55] and, in his essay, described the A.C. system very favourably. He also joined those prepared to pass confidential information to Pollen; the surviving copy of his comprehensive essay on Service fire control developments is to be found in the Pollen Papers.[56]

In his pamphlet, Pollen had also insisted that sights should be set automatically; Dreyer's response was that:

> We have tried [auto-sight setting] and now we are trying "follow-the-pointer" sights.
> ....
> A lot of rubbish re auto-transmission to the sights is loosely talked of.[57]

[53] 'Reflections on an Error of the Day', September 1908 in Jon Sumida (ed.) *The Pollen Papers* (London, 1984) p.180. For the list of recipients, see *PP*, pp.386-7; it included Wilson (but not Bacon or Dreyer).
[54] Dreyer to Hughes-Onslow 19 October 1908, typed transcript of what was probably a handwritten letter, T.173/91 Part VII.
[55] *IDNS*, pp.151 and 178.
[56] Hughes-Onslow, 'Fire Control' (*op. cit.*) Appendix A. The Pollen Papers also contains the confidential *Handbook for Fire Control Instruments 1906*.
[57] *PP*, 'Reflections' (*op. cit.*) p.190. Dreyer to Hughes-Onslow, 1908 (*op. cit.*).

The continuing failure of the Vyvyan-Newitt[58] and Siemens automatic sights may well have influenced Dreyer's preference for simple gear, particularly since the problems of setting sights automatically are very similar to those of remotely controlling a plotter arm from a rangefinder. However, his remarks on plotting methods are more difficult to explain.

> Whether the plotting is "Virtual Course" or is "True Course of Enemy" is quite a small issue and a matter of fancy waistcoats. The great thing is to use Range and Bearings. I spent a lot of time trying to develop Range Plotting without bearings but happily dropped it before the B.P. and told them all so.[59]

In the Autumn of 1908, without Chetwynd compasses, ships could only obtain compass bearings with the Kelvin compass, which did not give good results for plotting purposes. Dreyer had hoped that his scheme for plotting both ranges and range-rate against time would avoid any need for bearing, though even he later described it as 'only an expedient for the moment'. Unfortunately, *Excellent* found that the method of getting rates required 'a large number of ranges, which you were not likely to get when the guns were firing':[60] and, in any case, enemy speed and course could not be deduced from range-rate alone. It seems that these objections, Pollen's attack and the widespread preference afloat for course plotting together induced Dreyer to drop the more independent line which he had taken in his 'Hints'.

The introduction to the 1909 Admiralty pamphlet on fire control emphasised that plotting remained experimental, and warned that:

> ...the successful use of Plotting before fire is opened to set the Dumaresq correctly can be greatly discounted by the enemy's Admiral altering course..."together" at the moment that either side opens fire.

Nonetheless, much of the text was concerned with manual course plotting using the new Admiraty-pattern plotter, including ingenious though impracticable manual methods for plotting true courses while turning. It also described the new Dumaresq scales intended for keeping the instrument set while altering course.[61] Dreyer certainly wrote the introduction[62] and probably most of the rest of the pamphlet, and it appears that his inventive energies were focused mainly on the new instruments and on methods for

[58] Commander Arthur Vyell Vyvyan also received a copy of Pollen's pamphlet.
[59] Dreyer to Hughes-Onslow, 1908.
[60] Dreyer before RCAI, T.173/547 Part 17, pp.18-9.
[61] Admiralty, Gunnery Branch, *Information regarding Fire Control, Range Finding and Plotting*, 1909 in Ja010, AL.
[62] Dreyer to Field, 1923.

dealing with course changes. Also, after the visit to the Linotype works in July 1909, Dreyer was very much in favour of Pollen's automatic instruments.

> "The Apparatus consists of :- (a) An automatic plotting apparatus combined with a gyro controlled...R.F. similar to that tried in 'Ariadne' but considerably improved. (b)...a combined Range Clock and Transmitter....If this can be made to work satisfactorily it should prove a very valuable piece of apparatus. (c) Range and Deflection Spotting Correction transmitters....well worth a further trial now in view of the excellence of Mr. Isherwood's electrical transmission gear....(d)...electrically controlling [*sic*] gun sight.... This idea has been tried...but is worth another trial."[63]

Thus, given the widespread preference for course plotting and the high expectations in the NOD of Pollen's new designs, Dreyer had neither the opportunity nor, it seems, the inclination to revive rate plotting. Furthermore, he probably did not have the time. Many important advances had been made in those other areas for which he was responsible within the department (Chapter 3). He also claimed an important part in the adoption of the 13.5-inch gun;[64] however, this was probably an exaggeration and, indeed, with such a heavy workload, Dreyer may have been relieved of responsibility for turret mountings before he left the Admiralty (Appendix XX). Certainly, in September 1909, he was able to design and take out secret patents on two new fire control instruments, of which single examples were constructed by Elliott Brothers. The first appears to have been some form of tactical plotter (XVIII-3), but its main interest is that, like the Admiralty-pattern course plotter described in the 1909 pamphlet, it used a 'cone variable speed apparatus'. The second described a 'form of range keeper'.[65] When Dreyer visited the Linotype works with Captain Craig on 12 July 1909, he discussed with Pollen his suggestion for a 'hyperbolic clock' , which he was encouraged by the DNO to patent.[66] This device probably had a similar mechanism to that proposed by John Dreyer in early 1908 (XVIII-4), in which case its method of simulating virtual course was quite different from the Argo Clock Mark I. Presumably, Dreyer was advised to seek patent protection in case his own design should be developed subsequently. In the end, of course, neither the Dreyer nor the Pollen virtual course clocks had any direct influence on later designs.

While, even in September 1909, Dreyer was still patenting devices based on courses, Lieutenant Norman of *Arrogant* had made the next important advance by plotting

[63] Extract from Dreyer's report read to RCAI: T.173/547 Part 17, p.60.
[64] *Sea Heritage*, pp.59-60.
[65] Elphinstone to Director of Navy Contracts, 18 March 1914 and 'Notes' 1916 (*op. cit.*) in 'Fire Control Various Patents' (*op. cit.*). Swinburne, *Time and Range*, 1913 (*op. cit.*) pp.3-4 and 8.
[66] Dreyer before RCAI, T.173/547 Part 17, pp.61, 64 and 108-110.

bearings as well as ranges against time. On 11 June 1909, his report and the instruments he used were forwarded to the Admiralty,[67] while at some point he also went there to see Dreyer.[68] If their importance did not strike Dreyer immediately, by the time he left the Admiralty to take up a sea-going appointment, he must have fully recovered his belief in rate plotting.

VANGUARD AND THE ORIGINAL TABLE

> [In] November 1909 Commander Dreyer went to "Vanguard" as Executive Officer and rigged up an "Embryo" Dreyer Table
> Time and Range Plot
> Time and Bearing Plot
> Range Clock
> Dumaresq fitted with 2 Cross Sliders, to enable "Cross Cut" of 2 rates to be used.[69]

This assembly of instruments (it was not yet an integrated table) was completed and tried in the first half of 1910. By the beginning of July, the failure of the Argo true-course plotter in the *Natal* trials provided Dreyer with a particularly opportune moment to propose an alternative based on rate plotting. His 'Remarks' of 22 July described the *Vanguard* system. Ranges were plotted on one of the three patented plotters made in 1908, while a standard Admiralty-pattern course plotter was modified to plot bearings from the Chetwynd compass against time.[70] The two 'cross-sliders' fitted to the Dumaresq were celluloid strips at right angles, each with a centrally-inscribed black line. In good visibility:

> The Range clock is kept set for "mean Rangefinder Range of the moment" as shown by the Time and Range Instrument, and the rate as shown by a "Dumaresq" set by guesswork is first put on, and later this is superseded by the Rate shown by the Range and Time instrument.

However, Dreyer was equally concerned that his scheme should be able to deal as well as possible with more difficult conditions.

> The object of getting the "Dumaresq" set is to enable the Range Clock to be fed with Rates during periods when Rangefinding is interrupted by smoke etc. but where bearings...can be obtained.
> ...ALL systems of Plotting suffer from the defect that they rely on the enemy not altering his course and speed during...periods of interrupted Rangefinding.

He announced that:

[67] *Technical Comparison*, p.10.
[68] Dreyer before RCAI, T.173/547 Part 17, p.45.
[69] Frederic Dreyer, 'Summary', n.d. but 1925, p.11 in DRYR 2/1.
[70] The range bar, fixed at right angles to the driving screw, was recalibrated in degrees.

> This system...is meeting with success in this ship, having been used to Ranges over 13,000 yards.
> The Range clock is usually started with Rate and mean Range and the Deflection passed to the Guns about 1½ minutes after the first Range is obtained.

With the advantage of practical experience with rate-plotting at sea, Dreyer was now in a position to argue against its theoretical disadvantages.

> ...the general trend of thought afloat in connection with "Plotting" in the last two years has been too much in the direction of magnifying the importance of small geometrical deficiencies...instead of developing the most simple, practical and rapid system most likely to stand the stress of action. Thus, until recently, the general opinion with regard to the Time and Range system has been unduly biased against it by the fact that it often describes a curve instead of a straight line; the fact that it most rapidly and simply produces the mean Rangefinder Range of the moment...having been overlooked in favour of this purely Academic point.
> ...the fact that the dots on the two time instruments [may] describe curves...does not affect the accuracy...as the portions of the curves employed are small.
> During the recent P.Z. [tactical exercise] when this ship was continually altering course, a Time and Range instrument would have coped far more successfully with the Range-keeping than any other Instrument now in existence.

However, Dreyer was evidently still concerned about clock errors resulting from the transfer of rate from the Dumaresq to the clock only at intervals. His solution was to obtain the clock-rate from an extra Dumaresq set each minute (by reference to the rate from the bearing plot) to 'what the forecasted Bearing will be half-way through that minute'.

Dreyer, once again the principal advocate of rate plotting, nonetheless acknowledged that the Argo rangefinder mounting and transmission gear were the only means available to make rate plots automatically; he proposed:

> ...that Mr. Pollen may be asked to fit a 9-ft. Barr and Stroud's Rangefinder with his automatic Range Transmission, working a pencil to and fro on a Range bar...suitable for being mounted by ship's artificers...in this ship. This action could be taken without divulging to Mr. Pollen the nature of this instrument for which a secret patent is held...

Dreyer also recommended that:

> As this system shows promise of being a very good one [and] and I was the first to suggest this system which is clearly described at the foot of page 53 of the Pamphlet on "FIRE CONTROL"...G.4023/08...[71]

he should take out further secret patents covering the Time and Bearing Instrument and the method of setting the Dumaresq. Perhaps this was a disinterested suggestion intended to protect Service inventions: but, since the 1908 pamphlet did not mention a bearing

[71] Dreyer, 'Remarks', 1910 (*op. cit.*). The frequent underlining is typical of Dreyer's writings.

plot, it looks more like a deliberate and successful ploy to appropriate Norman's contribution to what, ever afterwards, were known as the Dreyer Tables.

On 13 August, Dreyer received a private letter (reproduced in Appendix XXI) from Joseph Henley of the DNO's department. With the other private correspondence between Dreyer and Henley, this letter demonstrates the close and friendly relationship between the Service inventor and the officer now responsible to the DNO for fire control; the contrast with Henley's suspicious attitude to Pollen is marked.[72] Sumida has cited this letter as evidence that Moore and others opposed automatic plotting, 'apparently preferring manual methods'.[73] The actual text shows that Henley (like Dreyer) was prepared to make use of 'Mr. P's Auto Receiver' but that the redesigned Argo gear would not be available for over a year. And, even if Moore questioned the practicability of automatic rate plotting in the short-term, he was in no doubt that the idea needed protecting. On the same day that Henley wrote to Dreyer, the DNO submitted:

> ...to direct Com^{r} Dreyer to take out a Secret patent for the whole system of Time and Range and Time and Bearing worked either automatically or manually....This action is considered desirable to protect the Admiralty from any developments of Mr. Pollen or others.[74]

In fact, Dreyer's next technical proposal was not the patent specification but resulted from trials of secondary control, for which *Vanguard* had been selected. These had been prompted by the provision of rangefinders in some turrets, which raised the possibility that fire could be controlled by the officer-of-the-turret. The experiments were conducted in August and culminated in a successful Special Battle Practice on the 31st, during which, at ranges sometimes exceeding 7,500 yards, 10 hits were made from 39 rounds fired. On 5 September, Dreyer submitted his 'Remarks on Local Turret Control' which recommended an installation comprising a 9-foot turret rangefinder in an armoured hood, a turret Dumaresq and a local control instrument (Plate 35). For the first time, he described a rate plotter which automatically recorded both rangefinder and clock ranges on the same chart. The device only had one differential gear (W) for correcting ranges, so (as explained in XVIII-5) spotting corrections normally had to be set in two steps, using I and then W. Nonetheless, Dreyer could claim that:

[72] Henley to Dreyer, 13 August 1910 in DRYR 2/1.
[73] *IDNS*, p.218.
[74] DNO's Minute 13 August 1910 and Dreyer to Captain Eustace, *Vanguard*, 12 October 1910 in 'Invention of Rangefinding System' in ADM 1/8131.

> It is the only instrument yet designed which enables the Rangekeeper to be kept instantly tuned up to the "mean Rangefinder Range and Rate of the moment" by inspection and entirely without calculation.

In this first description, Dreyer even acknowledged that:

> The advisability of fitting a red pencil to U to obtain a graphic record of the Gun Ranges which might help in correcting the Rate was pointed out to me by Rear-Admiral Peirse Inspector of Target Practice and Flag Commander W.W. Fisher when describing such a Time and Range fitting to them.[75]

However, when he resubmitted his proposal in October 1910, this frank admission had already been suppressed,[76] and it seems that he never mentioned it again. Like Norman's bearing plot, this 'ingenious method of "feedback" correction'[77] became yet one more feature of the tables named after Frederic Dreyer.

While praising the local control trials conducted by *Vanguard*, Admiral May did not support Dreyer's proposal for plotting instruments in turrets.[78] Even so, Dreyer was now able to use the local control instrument as the basis for a single instrument combining the separate components of the *Vanguard* system on a single base-plate; his patent application was submitted, as a Provisional Specification, on 23 September 1910.[79] This described two automatic plots, for ranges and bearings, placed side-by-side and sharing a common paper drive with manual alternative. The bearing pointer (indicating on a sliding scale) and pencil were mounted on a split nut engaging with the screw driven by the bearing receiver motor. This allowed plotting to commence with the pencil near the middle of the plot; thus the bearing plot could be made narrower. Bearings were to be received either from a rangefinder or from 'an independent bearing apparatus'. The instrument also incorporated a Dumaresq with celluloid 'cross-sliders'. The range part was very similar to the local control instrument: including the clockwork drive to the 'gun-range indicator', for which the following advantages had been claimed.

> The Rate of Change Clockwork can be direct and positive pinion drive as in the combined clock and transmitter being made by Messrs. Elliott Bros. to the designs of Captain Dreyer R.A. and myself, instead of by friction discs, cones and balls, as in other clocks.[80]

[75] Dreyer, 'Local Control' (*op. cit.*).
[76] 'Description' accompanying Dreyer to Eustace, 12 October 1910 (*op. cit.*).
[77] *IDNS*, p.220.
[78] Admiral W H May to the Secretary of the Admiralty, 1 October 1910 in 'Local Control of Turret Guns' (*op. cit.*).
[79] Patent 22,140/1910, Provisional Specification 23 September 1910, Complete Specification 12 April 1911. Copies in DRYR 2/1 and RCAI, T.173/91 Part III.
[80] Dreyer, 'Local Control', p.21. Note XVIII-4 suggests that this drive was part of Dreyer's range keeper, patented in 1909.

It is apparent that Dreyer was still collaborating with his brother and, as in the previous two years, working with Elliott Brothers to realise their ideas. However, this is the last document in which John is given any credit for ideas adopted in Frederic's fire control inventions.[81]

When Jellicoe took command of the Atlantic Fleet with his flag in *Prince of Wales*, Dreyer, on 20 December 1910, became his Flag Commander. Since 20 November, Dreyer had been appointed temporarily to the Admiralty,[82] which gave him an opportunity to work on the complete patent specification. On 14 December, he wrote to Keith Elphinstone of Elliott Brothers about the 'rate of change clockwork':

> ...have you any objection to my using the sketch of this fitment which you are going to send me shortly....the clockwork of the clock is after all the only part of this apparatus which is yours and if you like I will have that out and put in a cone and roller...or a disc and roller – any other sort of changeable speed gear in fact.[83]

Since clockwork normally drives directly at a single rate, it is difficult to imagine what Elphinstone had in mind: but, whatever it was, the Complete Specification of 12 April 1911 described the gun range screw as being driven by a constant-speed electric motor (the same which powered the plots) and 'a variable speed device [of unspecified type] situated under the Dumaresq'. However, in the accompanying sketch (Plate 36), there does not appear to be any space for such a device, while the remainder of the drive mechanism looks very like that of the local control instrument. Firstly, it appears that, in December, Elphinstone was still trying to devise a direct clockwork drive: but that, by April, while this improbable idea had been abandoned in favour of some form of variable speed drive, the details were then far from settled. Secondly, Dreyer's letter suggests that he was largely unconcerned about which type of drive should be employed; since he was at sea when the decision was made, the conventional disc-and-roller eventually used was probably selected by Elphinstone alone.

Like the proposal for the local control instrument, the Complete Specification describes only a single differential (now with a frictionally-coupled pointer 'which can be re-zeroed at any time') for correcting the gun-range. As before, the gun-range screw and pointer could be displaced laterally by an amount shown on the 'spotting scale'; thus

[81] Frederic's son, Admiral Sir Desmond Dreyer, confirmed that the 'Dreyer Table...was developed by my father with considerable help from his brother...later Major General J. T. Dreyer': 'Early Development in Naval Fire Control, *The Naval Review*, July 1986, p.238. The present author is most grateful for advice on this chapter from Commander Christopher Dreyer, the son of John Dreyer.
[82] *Sea Heritage*, pp.62-3. Jellicoe to Dreyer, 10 November 1910 in DRYR 3/1 and 3/2.
[83] Quoted by Dreyer before RCAI, T.173/547 Part 17, p.105.

applying a simple spotting correction remained a two-stage operation. The Dumaresq (apparently a modified Mark III) had a fixed bearing plate, while the fore-and-aft bar (with the outer ring on which it was mounted) rotated. The clock-rate was determined by the small pointer moving in the transverse slot cut in the bearing plate. Hence:

> ...the Rate need not be actually read off but can be set on the Gun Range Indicator [the clock] by turning the [hand-wheel] so as to keep the pointer opposite to the bows of the dummy enemy's ship.[84]

The essential features of this scheme had been put forward in October 1910 by Gunner J W Newland of *Excellent* as part of a proposal for a mechanical connection between a Dumaresq Mark II and a Vickers clock. The DNO decided not to patent the idea, but Dreyer might well have heard about it, or even read the papers, when attached to the Admiralty in December.[85]

This appointment also enabled him to learn about the Anschütz gyro compass (Elliott Brothers were the British agents), which was about to undergo trials in his new ship (as well as in *Neptune*).[86] On 2 December, Dreyer submitted a proposal for

> ...obtaining, transmitting and plotting...the bearings of an Enemy from an Anshutz [*sic*] Gyro Compass Receiver Card mounted inside a Rangefinder mounting or on any other suitable stand....
> I described this fitting to Mr. Elphinstone of Messrs. Elliott Bros. when visiting their works at Lewisham this afternoon with Lieutenant J.C.W. Henley to inspect the Gyro Compass for the "Prince of Wales". Mr. Elphinstone informed me that he could easily incorporate this in the set of Gyro Compass Gear now under manufacture.[87]

Dreyer's RCAI evidence confirmed that the transmission scheme (Plate 37 and XVIII-6) was actually applied to the rangefinder mounting.[88] Then on 21 February 1911, Henley wrote privately to Dreyer:

> As the T&R & T&B will go to Prince of Wales I think it would be better to get a B&S [Barr and Stroud] Transmission as we have already got the Bearing Trans. from the Gyro Rec^r [Receiver].[89]

At this time, Argo were still some months away from completing the prototype production mounting and were still developing the step-by-step transmission scheme that would eventually be used for the Argo plotters: and, in any case, it was not intended to supply

[84] Patent 22,140/1910, complete specification (*op. cit.*) pp.6-7, 10 and diagram.
[85] For correspondence, see 'Invention for a device for applying the Dumaresq to the Range Clock' in ADM 1/8131.
[86] A E Fanning, *Steady as She Goes* (London, 1986) p.177.
[87] Dreyer to DNO, 2 December 1910 in T.173/91 Part III.
[88] Dreyer before RCAI, T.173/547 Part 17, p.86.
[89] Henley to Dreyer 21 February 1911 in DRYR 2/1.

the Argo mounting to battleships earlier than *Dreadnought*.[90] Thus, despite earlier expectations, the ranges and bearings for this first Dreyer table were neither taken nor transmitted with equipment from Pollen's company.

By 1 July 1911, Dreyer was able to advise Elphinstone that 'The Time and Bearing Chrono' had arrived safely in *Prince of Wales*, although their correspondence shows that the design of the range components of the table was still being finalised. Dreyer also requested a 'Connection from Gyro compass to ship's head ring of Dumaresq'; as he later insisted, this was the first mention of the feature that would make the Mark III Table helm-free (though it remained dependent on the manual transfer of rates). Henley had taken up the proposal by 4 July, but on the 10th, he informed Dreyer that, although 'Elphinstone...sees no difficulty...D.N.O. is rather opposed to making any further alteration to your instrument.'[91] Then on 19 July, Dreyer proposed another major enhancement, the addition of a bearing clock: though the mechanism he suggested, a hand-worked variable-speed drive based on a simple cone-and-roller 'similar to the one you fitted to the Ady. [Admiralty] Screw Bar plotting instrument',[92] was wholly unsuitable for a rate which might be positive or negative. It is curious that this important proposal was placed in evidence before the RCAI only as an extract from a letter to an unnamed recipient: though 'you' was probably Elphinstone.[93] Thus the letter may have been a private one containing some embarrassing remarks about the bearing clock already proposed by Argo. In any case, for the time being Dreyer's impractical idea went no further; on 24 July, Henley reported only that:

> Re: Gyro Connection for Dumaresq or Chrono
>
> ....
>
> Elphinstone said that nearly all the parts of the present chrono are made and that if the Gyro connection were fitted there would entail considerable delay. So D.N.O. decided not to fit it...but concurs in the addn [addition] if any more instruments are ordered.[94]

Elliotts were then able to complete the remaining components of the table, which was installed in *Prince of Wales* on 30 September. After extended trials, and despite an undistinguished placing in Battle Practice,[95] Captain Hopwood submitted a very

[90] *DNO for Successor*, May 1912, p.15.
[91] Dreyer to Elphinstone, 1 July 1911, Elphinstone to Dreyer, 3 and 4 July and Henley to Dreyer, 10 July 1911 in T.173/91 Part III. Dreyer 'Summary'.
[92] 'Extract from Letter dated 19/7/11 from Com. Dreyer' in T.173/91 Part III.
[93] If it is assumed, as was probably the case, that Elliotts made the Admiralty course plotter.
[94] Henley to Dreyer 24 July 1911 in T.173/91 Part III.
[95] *Prince of Wales* was a poor 7th out of 9 ships in the Battle Practice of the Atlantic Fleet and 5th Cruiser Squadron: Admiralty, Gunnery Branch, *Results of Battle Practice in His Majesty's Fleet 1911*, AL.

favourable report, which was fully endorsed by Jellicoe. The heavy underlining in the Captain's letter suggests that the Flag Commander had a hand in its drafting: but it also quoted remarks 'included by the Inspector of Target Practice in his comments on the "PRINCE OF WALES" Battle Practice carried out on 11 November'.

> "Commander F.C. Dreyer's Fire Control Instrument appears to be of considerable assistance in obtaining a correct Rate, and in maintaining the mean rangefinder range until fire is opened. The Correct rate was obtained on both runs".[96]

Hopwood's letter mentioned that, during Battle Practice, the lateral movement of the gun-range screw had proved its usefulness when smoke interference forced a change from the fore to the after rangefinder; '...the difference in adjustment between the two rangefinders can be immediately absorbed without calculation'. Attention was also drawn to '...the record of the instrument during the...firing...on 2 November 1911' which showed 'the success with which the Range was kept...during a 13 point alteration of own ship's course'.[97]

In 1918, when Dreyer himself was DNO, a lavish *Handbook* on the Dreyer Tables was produced; doubtless at his insistence, it included a photograph of what by then was called the Original Table.[98] The general layout and construction (Plate 38) was clearly the same as that illustrated in the complete patent specification. The screws of both plotters were driven by large receiver motors, permitting automatic plotting of ranges and bearings transmitted from the Barr and Stroud rangefinder mounting. The Dumaresq was now the latest model, the Mark VI, which probably explains why the rate could be kept successfully even through large turns.[99] The Dumaresq had also been raised sufficiently to accommodate the disc-and-roller variable speed drive: though nothing can be seen of the clock mechanism, the tuning differential or the electric motor driving the clock disc and the paper winding rollers.[100] Unexpectedly, the photograph shows clearly that the gun-range screw was driven by a third receiver motor, apparently identical to those for

[96] The ITP's emphasis suggests that there may have been systematic errors in the *range*.
[97] Hopwood to VAC Atlantic Fleet, 20 November 1911 and VAC Atlantic Fleet to the Secretary, Admiralty, 25 November 1911 in T. 173/91 Part III.
[98] *Handbook of Captain F.C. Dreyer's Fire Control Tables 1918*, Plate 45, AL. Dreyer was DNO from 1 March 1917: *Sea Heritage*, p.234.
[99] 'The parts to complete the Dumaresq to Mark VI' were sent from Elliotts before the end of October: Elphinstone to Dreyer, 30 October 1911, T.173/91 Part III.
[100] Captain Tower's evidence to the RCAI mentions the *alternative* hand drive (T.173/547 Part 11, p.22), which suggests that, as in the complete patent specification and the Mark III table, the primary drive was an electric motor.

range and bearing.[101] This feature is confirmed by a note (almost certainly by Dreyer) to Hopwood's letter.

> Although the instrument...worked excellently...it would be better...to have all future instruments with direct mechanical drive for the range clock portion (instead of electric) as originally designed by the Inventor. This appears likely to be more acceptable in the Service, as Electrical gear is often looked on with suspicion.[102]

This might be seized on as an instance of naval prejudice against new technology: yet Keith Elphinstone had already expressed exactly the same view.

> Mechanical Devices usually have troubles you can see - Electrical Devices have the same number of troubles which you can see [and] double the number...which you cannot.

He also gave his reasons for initially adopting the indirect electric drive, in which the clock roller must have driven a commutating transmitter switch:

> ...a mechanical drive is the thing to aim at, but it looked so awkward and cumbersome on paper, and there seemed such a doubt as to whether the roller would really drive it from a rotating disc including the Differential Gear and the Spotting Correction....Now that one has seen the thing at work, I don't see the least difficulty in making the drive mechanical...and this I propose to do in the new Drawings.[103]

THE MARK I BOARD

Before describing these new table designs, it is necessary to mention a proposal which Dreyer submitted formally through Jellicoe on 12 October. This described a 'Fire Control Board' for use in less important ships, which, Dreyer proposed, should be designated as Mark I to differentiate it from the 'Mark II' on trial in *Prince of Wales* (Elphinstone later confirmed that the Original Table had been known for a time as Mark II).[104] Functionally, this 'board' (Plate 39) was very like the local control instrument from a year earlier,[105] but with the addition of a Mark VI Dumaresq, modified as in the Original Table. The range-rate pointer was coupled mechanically to a Vickers clock, on which the range scale was replaced by a plain ring with an engraved arrow. By turning a handle to follow the clock hand with the arrow, an operator also drove the screw of the range plot through a tuning differential. The paper was moved by hand, while automatic plotting of rangefinder ranges was proposed only as an option.[106] The surviving sources provide no

[101] For Elliotts as the supplier of these motors, see XVIII-10.
[102] Hopwood to VAC Atlantic (*op. cit.*).
[103] Elphinstone to Dreyer, 11 October 1911 in T.173/91 Part III.
[104] Elphinstone to Dof C, 1916 (*op. cit.*).
[105] A drawing of the latter was attached to Dreyer's letter
[106] Dreyer to Jellicoe, 12 October 1911 with 'Description of the Apparatus' in T.173/91 Part III.

indications that any immediate action was taken on this proposal, probably because priority was given to the new table for important ships; however, in the 'Mark I Board', Dreyer had already laid down the principal features of the later Mark I Table.

DREYER TABLE MARK III

On 11 October, shortly after the delivery of the Original Table, Elphinstone wrote to Dreyer:

> I have already got instructions from the D.N.O.'s Office to prepare a specification and Drawing...should another instrument be ordered as soon as a report comes in as regards the first one.
>
> ....
>
> I should be glad if you could criticise the Schedule sent as quickly as possible.

On the 30th, Elphinstone sent 'an amended specification...two copies of...a perspective sketch I made and a couple of Schedules of the Parts'. In this letter, he also described his only known visit to Argo's premises.

> I was at York on Thursday - we sent up a Gyro Compass Receiver fitted with an attachment to control the Azimuth position of an R.F. and from trials there it looks like a successful application of the Gyro Compass Gear - I hope it will prove to be so in practice at sea.[107]

This occasion, which was quite different from Henley's visit on 11 October to see the Argo clock under construction, was clearly related to the co-operation between Argo and Elliotts, the British agents for Anschütz, which was necessary to fit gyro-compass receivers in the last 20 Argo rangefinder mountings. It is most unlikely that Argo would have shown the new clock to their principal competitor in fire control, and, if they had, Elphinstone would surely have at least mentioned it in his unofficial letter to Dreyer. Nor has any other evidence been found that, at this time, Elphinstone was familiar with the still-evolving design (let alone the drawings) of the Argo clock.[108]

Elphinstone's sketch and schedule (both dated 28 October) were forwarded with Captain Hopwood's letter to the Admiralty on 25 November. On 7 December, the DNO, Captain Moore, added the following recommendation.

> At a rough estimate the cost of the Argo Co's installation, i.e. rate plotter and clock will not be less than £1,200 whereas the Dreyer instrument doing the same duties will cost about £300.
>
> It is considered most desirable that the "Orion" and "Lion" classes should be provided with these instruments at once. The "Orion" herself will be fitted with the Argo Co's

[107] Elphinstone to Dreyer, 11 and 30 October 1911 in T.173/91 Part III.

[108] Compare these conclusions with *IDNS*, p.219 (quoted in Chapter 1).

> gear for trial so that it leaves five ships to be provided.
> It is therefore submitted that Messrs. Elliott Bros. may be requested to tender for five of the improved instruments....[109]

In his specifications and schedules, Elphinstone called the new design the 'Seven Part Recorder', to emphasise its modular construction. Different equipment schedules were given for ships with and without either Argo rangefinder mountings or gyro-compasses (XVIII-7). As may be seen from Plate 40, the general layout was very similar to the Original Table; as previously, the gun-range screw could be shifted laterally by a rack, though now the 'spotting correction' was set on the small circular scale 41. The gyro-compass receiver 83A controlled the motor 83 which applied any change in course to the Dumaresq's compass ring. The range clock was now coupled mechanically to the gun-range screw through a tuning differential gearbox, while the new bearing clock was connected (by means unspecified) to the Dumaresq. The bearing-rate scales were arranged so that the rate from the bearing-plot could be easily set on the bearing clock. Elphinstone did not mention the Dumaresq as an alternative source of bearing rate, and the design had no means for converting speed-across in knots to bearing-rate in degrees-per-minute.

The order for five improved tables was placed with Elliott Brothers on 27 February 1912; the actual price for each complete table was £635.[110] In December 1911, Jellicoe, on taking command of the Second Division of the Home Fleet, had shifted his flag to *Hercules*. Dreyer continued to serve as his Flag Commander and took the Original Table with him;[111] it was probably still in that ship in February 1916, although, by 1918, it had been replaced.[112] Since he was at sea, Dreyer can have contributed little while Elphinstone developed his ideas from the 'Seven Part Recorder' into a finished design. Working drawings had been completed by May 1912,[113] the first production model being installed, probably in *Monarch*, before the end of the year; in February 1913, she was said

[109] Elliott Bros. 'Seven Part Recorder' revised 28 October 1911 (with sketch): Jellicoe to Secretary, Admiralty 25 November 1911 and DNO's Minute, 7 December 1911, all in T.173/91 Part III.
[110] Dreyer, 'Summary' p.13: 'Details of Clocks and Rate Plotters on order' attached to F W. Black, 'ARGO COMPANY, Present Situation' n.d. but probably December 1912 in Mountbatten Papers, MB1/T22/174, University of Southampton.
[111] *IDNS*, pp. 220-1: *Technical Comparison*, pp.12 and 39.
[112] 'Ships in which Dreyer's Fire control is fitted or is being fitted' attached to 'Recommendations of the Admiralty Members of the Ordnance Committee at a Meeting 10.2.16 concerning Dreyer's award', DRYR 2/1. Here, the five ships which received the new table are listed under the heading 'Mark II', but they are headed by *Hercules*, marked by an asterisk. By 1918, *Hercules* had a Mark I table: *Handbook 1918*, (*op. cit.*) p.3.
[113] Dreyer, 'Summary' p.13.

to have 'the most up-to-date set of this apparatus... afloat'. The remaining four units were fitted in *Lion*, *Princess Royal*, *Thunderer* and (rather than in *Conqueror* as originally intended) in *King George V*.[114] By March 1914, the new design was known as the Mark III Table,[115] and it will be convenient to use this designation henceforward.

In December 1912, Dreyer was appointed to command the new cruiser *Amphion*, but, while waiting for his ship to commission (in April 1913), he once again returned to the Admiralty.[116] At this time, a number of reports were being produced to justify Admiralty policy on the Pollen Aim Correction System. Dreyer collaborated with Commander C V Usborne (the DNO's assistant responsible for fire control) on the *Technical History and Technical Comparison* between the Dreyer and Argo systems: and himself contributed a detailed description of the new instrument, which in turn quoted extensively from its instruction pamphlet.[117] As can be seen in Plates 41 and 42, Elphinsone had rearranged the main components of the table; the Mark VI Dumaresq (modified as in the Original Table), with the variable-speed drives of the range and bearing clocks beneath it, was now placed between the two plots. Above the Dumaresq (XVIII-8), a fixed panel carried, on its front, the speed indicator of the Forbes log and a gyro-compass receiver (Plate 43). On the back, a 'relay device' controlled an electric motor which, through a flexible drive shaft, rotated the fore-and-aft bar relative to the Dumaresq's compass ring by an amount equal to the change in own ship's course.[118] The relay was another example of a 'bang-bang' servo and, in the form supplied by Elliotts with the Anschütz receiver, the motor tended to hunt somewhat, probably by ¼° or so.[119] The resultant oscillations in the indications of the Dumaresq were imperceptible except for the largest rates (XVIII-9): but, even then, it should not have been difficult to judge the mean values when reading the rates by eye.

Dreyer recommended that the Argo mounting 'should have a trainer's telescope fitted to it to enable a separate trainer to be used' and he 'expected that the Training

[114] *Technical Comparison*, pp.11,12 and 55.
[115] Elphinstone to DofC, 1914 (*op. cit.*).
[116] Dreyer to DNO, 19 December 1912 in T.173/91 Part III. *Sea Heritage*, p.72. Dreyer to Jellicoe, 14 June 1913 in DRYR 4/3.
[117] *Technical Comparison*, p.39.
[118] *Technical Comparison*, pp.41-2, 46, 50 and Figs. V/1,3,6 and 7. *Handbook 1918*, pp.17, 49 and Plate 23. All five ships with Dreyer Tables Mark III were early recipients of Anschütz gyro-compasses: Fanning, *Steady As She Goes* (*op. cit.*) p.178.
[119] *Technical Comparison*, Fig.V/9. 'Rate of Change of Bearing Instrument' appended to P M S Blackett, 'Naval Diary 1914-1918', transcribed by and courtesy of Dr N M Blackett.

Number will get a far larger number of observations than the Range Taker will'. Thus the pencils of the plots were controlled separately by the two rangefinder operators, so that all ranges and bearings could be plotted automatically as they were received by the two large receiver motors. Only the Argo mounting was mentioned as a source of bearings; however, if ranges could not be obtained there, ranges from a turret rangefinder could be plotted manually instead. Dreyer also suggested that:

> It may be found possible to plot the ranges from more than one Range finder at one and the same time

though clearly this was not yet an established method.[120]

In their part of the Pollen Aim Correction System report, the Contracts Department insisted:

> It is...only fair to the Service to state that not until the end of 1912 was automatic range plotting made reliable (this was accomplished by Messrs. Elliott Bros.) and that even now in 1913 Mr. Pollen has not yet succeeded in himself producing a reliable instrument for automatic range plotting.[121]

On both the Original Table and the Mark III, automatic plotting (of bearings as well as ranges) depended on the large step-by-step receiver motors developing sufficient torque to drive the plotting screws and attachments. The diagram of electrical connections shows that these motors were similar in operation to the R-type motor supplied by Elliotts with gyro-compass installations (XVIII-10), which in turn was a modified version of the Anschütz design.[122] Thus it appears that Elphinstone's firm adapted the gyro-compass technology to create the large plotting motors, which, perhaps after some problems in 1912, proved more reliable than the clutch-based receivers used by Argo.

As previously, the rate on the range clock was set by following the Dumaresq indications with the pointer in the transverse slot. The range clock drove the clock-range screw through a differential; thus the clock-range, as indicated by the clock-range pointer and pencil, could be corrected with the tuning handle. The Mark III also introduced a second differential gearbox, positioned at the other end of the clock-range screw, with its output shaft driving the gun-range indicator and transmitter. Hence, with the aid of its dial and pointers, an operator could apply spotting corrections to the clock-range. The

[120] *Technical Comparison*, pp.42-4, 46-7 and Fig.V/9.

[121] *Pollen Aim Corrector System: General Grounds of Admiralty Policy and Historical Record of Business Negotiation*, February 1913, p.3. P.1024, AL

[122] *Technical Comparison*, Fig. V/9. Hugh Clausen, 'Notes on Step by Step Transmission System' (Evershed and Vignolles Ltd. 1962), p.11, CLSN 1/7, CC.

gun-range was then transmitted, in equal steps, to a manually-worked follow-the-pointer transmitter with interchangeable cams; each cam converted the equal range steps received from the table into the unequal steps in gun elevation appropriate to one nature of charge (full, reduced, sub-calibre and aiming-rifle). The introduction of the spotting differential meant that spotting corrections could be set without disturbing the plot of clock-ranges. However, there was still a need to be able to adjust the clock-range pencil without altering the gun-range: for example when switching from the Argo to a turret rangefinder. Instead of shifting the whole screw bodily, the pointer and pencil were now mounted on a small carriage which could be moved along the screw by means of a knurled head and dial.

The range-rate disc with parallel wires measured the slopes of the rangefinder and clock range plots. Any divergence indicated how the Dumaresq range-rate should be adjusted to improve the accuracy of the cross-cut.[123]

The rate of the bearing clock was set by hand using the knob and linear scale on the front of the casing; the scale was calibrated between ±15°/min. The clock's output shaft was coupled through a clutch to the compass ring of the Dumaresq (XIII-8); at any time, the bearing clock could be disconnected and the predicted target bearing altered by hand. Observed target compass bearings were transmitted, in ¼° steps, to the bearing plot. This could be narrower than the range plot,[124] since the bearing scale was engraved on an endless loop, while the pointer and pencil (which were attached to a split nut) could be given any starting position. Bearing-rate, in °/min., was measured with a second rate-measuring disc with parallel wires. This disc was linked to a sliding pointer moving across a set of curves, of constant speed-across, engraved on a drum (Plate 44); the drum was rotated by a shaft connected to the clock range screw. The curves were constructed so that, at all ranges, the drum pointer indicated the speed-across which corresponded to the bearing-rate indicated by the scale of the bearing-rate disc. Thus a means was provided to convert between and compare plotted bearing-rate and Dumaresq speed-across, without calculation.[125]

[123] *Technical Comparison*, pp.41-2, 45-6, 49 and Fig.V/1, 3, 5, 6 and 7.
[124] 15 compared with 36 inches: *Technical* Comparison, p.48.
[125] *Technical Comparison*, pp.42, 44-5, 49-50 and Figs. V/1, 3, 7 and 8. *Handbook 1918*, p.18, Plates 6 and 23. Admiralty, Technical History Section, *The Technical History and Index*, 'Fire Control in H.M. Ships', December 1919, p.27, AL. For additional technical details of the Mark III and later Dreyer Tables, see William Schleihauf, 'The Dumaresq and the Dreyer' in *Warship International*, No. 3, 2000 (advanced copy gratefully acknowledged).

The methods of using the Mark III Table were set out in Dreyer's pamphlet. At the start of an engagement:

> Set the Dumaresq for guessed course and speed of Enemy and bearing of Enemy...as ordered from aloft [and for own speed from the Forbes log].
> Set {the fore-and-aft bar} to True Course of own Ship and clutch in the {gyro-compass connection}.
> Turn the {rate handle}...to keep {the range-rate pointer} opposite to {the enemy bow pointer} (the Range Rates shown by the Dumaresq are thus put on the Range Clock)...[126]

Using the tuning handle, set the clock-range pencil to indicate the initial target range, which may be an estimate ordered by the Control Officer aloft. Put on the Spotting Differential 'the anticipated difference between True and Gun Range'. On the bearing clock:

> ...set the Bearing Rate for the range in use as deduced from the Dumaresq Deflection...

With both clocks now started and until fire is opened:

> ...turn the {tuning handle}...as necessary to keep {the clock-range pencil} by inspection in agreement with the *Mean Range Finder Range of the Moment as shown by the Range Dots.*

Likewise, if the target bearing indicated by the Dumaresq diverged from the mean plotted bearing:

> The movement due to {the bearing clock} can...be overcome and corrected...at any time by manually turning the milled head [which also disengaged the bearing clock from the compass ring].

If clock ranges or bearings diverged from the plotted mean values, the table operators proposed a new value for range-rate or speed-across, also indicating whether the recommendation was based on a good, fair or indifferent plot. However:

> *It should be clearly understood that the Range Keeper in the Control Position in use is the Master Rate Operator* and therefore no alterations to the Course and Speed of Enemy or any Rate...can be made without his permission.

The Range Keeper could either order the recommended change or some other value more in accord with his observations. If (say) the range-rate was altered, the new setting would be used unchanged until the Range Keeper also ordered a new value for speed-across; thus a new cross-cut was established (in effect, new settings of enemy course and speed), after which the clocks were again set with the rates indicated by the Dumaresq.[127]

[126] The {} brackets show where descriptions have been substituted for reference letters. The [ ] brackets, as usual, indicate other interpolations.
[127] *Technical Comparison*, pp.42-5.

Once firing began, there was a danger that range tuning at the table might conflict with the range changes ordered by the spotter. Thus every tuning alteration was called up from the table to the Spotting Officer: who could, if he wished, cancel it by ordering a spotting correction in the opposite sense. Similarly, he did not order a rate spotting correction without reference to the officer in charge of the table.[128]

Dreyer emphasised that:

> The Fore and Aft Bar of the Dumaresq being kept Oriented in Space by the connection to the Gyro Compass, THE RANGE CAN BE KEPT WHILE OWN SHIP IS TURNING.

During the turn, the bearing clock kept the Dumaresq correctly set for inclination. As Dreyer made clear, the bearing clock also kept the target bearing, should observations be interrupted.

> Whenever the enemy completely disappears *i.e. the moment the bearing operator...ceases to receive bearings*, he reads off the Dumaresq deflection [the speed-across] and sets the corresponding true Bearing Rate...on the bearing [clock's rate] scale....He must then watch the Dumaresq for changes in deflection, so that the correspondingly altered bearing rate may be set on the bearing [rate] scale. The instrument will thus be kept correctly set for bearing of enemy, although the latter is not visible.
>
> NOTE.—Any alteration in course or speed of enemy while out of sight, or any errors in estimating enemy's course and speed, previous to his disappearing on a steady course, will, of course, produce errors in the forecasted range or bearing, or both...

Dreyer also made a virtue of the 'non-positive' connections between the Dumaresq and the clocks, since they allowed the two parts of the table to be set to different rates.[129] He did not discuss the possibility of errors arising from the manual transfer of range-rate, probably because it was not of practical concern. With the rate lines on the Dumaresq spaced at intervals of 100 yds/min., it would normally have been easy to follow the changes of rate in steps of 25 yds/min; thus the range error due to stepwise transfer would have increased by only 12½ yds/min. (XVIII-11). Even when two 25-knot ships passed beam-to-beam at 8,000 yards, the range-rate changed by 25 yds/min. in no less than 4.2 seconds, still time enough to follow the rate in 25 yds/min. steps. However, if the ship was also altering course unfavourably, this interval could be reduced to 2.3 seconds (Appendix

[128] '*Home Fleet General Order, 14. Fire Control Organisation*, 5 November 1913 (p.3) with Enclosure No. II, 'Instructions defining the latitude allowed to the transmitting station officer...' in DRAX 1/9, CC. See also Dreyer, 'Remarks' (1910) pp.6-7.

[129] *Technical Comparison*, pp.41 and 46-7. He even suggested that, by allowing the rate to lag somewhat, the operator could correct for 'slip': 'Some comparisons made between the Argo Clock and the Fire Control table in "Monarch" ', T.173/91 Part VII; the style and content, and wording (in places almost identical with Dreyer's technical description), indicate that this was written by Dreyer, probably in late 1912.

III); this might demand steps of 50 yds/min. but, even so, the total error accumulating during a turn of two minutes would not much exceed 50 yards.[130]

Setting the bearing-clock for rate was not so easy. Firstly, the speed-across had to be read from the Dumaresq by eye alone. Secondly, the pointer linked to the bearing-rate disc had to be positioned against the drum so that it indicated the same speed-across. Thirdly, the corresponding bearing-rate was read from the scale on the disc and set on the rate scale of the bearing clock. It might be supposed that the only practicable method was to alter the clock-rate in steps only when the Dumaresq pointer crossed either a speed-across line or a mid-point between these lines i.e. each time the speed-across changed by 2 knots. There was time enough for this when courses were steady; at worst, when two 25-knot ships were on opposite courses, the speed-across never changed by 2 knots in less than 29 seconds (XVIII-11). Even so, as with range-rate, a stepwise transfer of bearing-rate must have resulted in the clock-bearing lagging the true bearing: although this bearing lag only 'fed-through' to produce a range-rate error if the speed-across was high (XVIII-12). In February 1913, a Mark III Table was set up in Elliott Brothers' Westminster office to simulate the case of two ships on opposite courses. The first test represented two 15-knot ships passing beam-to-beam at 7,000 yards; the target was assumed to become invisible when the range was still 12,000 yards, after which, for almost 10 minutes, the table kept the range and bearing without operator intervention until the time of passing beam-to-beam. Yet the range error was then only 70 yards,[131] less than the predicted error from range-rate steps of 25 yards. This suggests that skilled operators, albeit in ideal surroundings, could transfer both range and bearing rates in very small steps, in effect, almost continuously.

Despite this impressive performance, it must still be doubted whether at sea, and especially in battle, bearings could be kept so accurately. The bearing clock was, nonetheless, a useful feature. While the target was visible, it provided a check on the deflection component of the cross-cut: while any errors in clock-bearing were readily correctable from observations.

[130] When own ship alters course, range is no longer a hyperbolic function of time. However, Appendix XXII shows that the same simple approximate relationship between error-rate and rate step size can still be used, though in extreme conditions the approximation is less exact.

[131] *Technical Comparison*, p.61 and Figs.11 and 12. The test was repeated for two 30-knot ships. Until just before the passing point, the table kept the range as accurately as before, but the range error then increased to 140 yards in only one minute. However, the bearing rate was then 16.6 °/min. which exceeded the maximum rate of the bearing clock.

> ...it will be necessary from time to time to unclutch the automatic drive and correct the position of the compass ring. The need for this will be indicated by noticing whether the bearing of the enemy as shown on the Dumaresq corresponds to the observed bearing recorded by...the bearing plot.[132]

If the target became obscured, firing ceased (blind firing was not possible before the introduction of the GDT gear). Even so, provided 'the enemy is obliging enough <u>not</u> to alter course or speed while out of sight',[133] the bearing clock could keep the bearing, at least approximately, even if own ship changed course.[134] Thus, when the target reappeared, the range and rate might not be exact, but they would be near enough to correct by spotting the first few salvoes.

DREYER TABLE MARK II

As the deliveries of the Mark III tables were commencing:

> ... it became necessary to decide without awaiting the trials in "Orion" what form of control instrument should be fitted in "King George" class. It was decided to order for these ships sets consisting of a Pollen clock and a Dreyer Time and Range table. It was also considered that a Time and Bearing table would not be necessary with the clock ... As a result of [the *Orion*] trials, the clock was favourably reported on but it was shown necessary to use a Time and Bearing as well as a Time and Range table with it and it was decided that these should be of the Commander Dreyer type and manufactured by Elliott Bros.
>
> The Pollen Time and Range and Time and Bearing tables [*sic*] were not satisfactory...

and, in any case, Pollen's price, even for a time-and-range plotter, had been uncompetitive. In February 1913, it had already been 'decided to make in Portsmouth Dockyard the necessary apparatus for connecting [Dreyer's plotting] gear to the Argo range-finder mountings and clock', and that the Argo clocks would be supplied to *Ajax*, *Centurion* and *Audacious* (*King George V* class), *Conqueror* (*Orion* class) and *Queen Mary*.[135] When the Dreyer Table Handbook was published in 1918, the combination of Argo clock with Dreyer rate plotters had been designated the Dreyer Table Mark II,[136] in which: 'the clock range screw is run by an electric motor controlled by a commutator from clock range in argo [*sic*] clock'.[137] Unfortunately, apart from an indication that, by early 1914,

[132] *Handbook 1918*, p.49.
[133] Dreyer, 'Some comparisons...' (*op. cit.*).
[134] The large change in bearing-rate induced by a change of own course might force bearing-rate steps of 4 rather than 2 knots: XVIII-11.
[135] *Technical Comparison*, p.11-12: *Record of Business* (*op. cit.*) p.15.
[136] In 'Ships...Dreyer's fire control...fitted' (1916), the tables with Argo clocks are called Mark III*. By 1918, this number had been adopted for a more modern table.
[137] *Handbook 1918*, p.15.

Queen Mary was already fitted with standard Elliott-type cam-operated transmitters,[138] no further details of the Mark II Table have been found. However, a reasonable conjecture (XVIII-13) is that the peculiar arrangements for setting spotting corrections and transmitting gun ranges, which are described in the contemporaneous handbook for the Argo Clock Mark IV, were replaced by something very like the clock-range plot and spotting differential of the Dreyer Table Mark III.

RANGEFINDER CONTROL

The ships of the *Orion* and *King George V* classes were formed into the Second Battle Squadron (2BS).[139] All these latest battleships were equipped with rate plotters coupled to either Dreyer or Argo clocks, and, as described in Chapter 3, with multiple rangefinders. As might be expected, the new system of 'rangefinder control...has been very largely introduced and developed in the 2nd Battle Squadron' which had 'many more rangefinders than any other'.[140] The system was promulgated to the Home Fleet in a General Order from Admiral Callaghan dated 5 November 1913 as 'a method considered to promise very well', especially though not exclusively for the latest ships.

> The readings from as many R.F.s as possible are plotted on moving paper on the Dreyer table, the Argo R.F. being plotted automatically, and the others by hand. If the R.F.s are well together, it has been found that there should be a zone of dots proceeding across the paper, their direction depending on the rate of increase or decrease of the range, and it is then easy to determine by inspection the mean of these ranges.
>
> ....
>
> ...alteration of course and speed of the enemy is quickly made apparent in the different aspect of the R.F. plots, from which the clock range can be corrected, the *correction of the rate being of secondary importance so long as the range is maintained and hitting continued.*

It was also claimed that the method reduced the dependence on spotting and that after 'straddling, and not being entirely dependent on rate, the maximum rate of fire may be developed'. However, these benefits depended on a constant stream of accurate ranges, which were unlikely to be obtained except:

> ...under favourable conditions of weather and visibility at ranges below 10,000 yards [when] the rangefinders are well together. These conditions however can *rarely* be those of action as, when the visibility is good, fire will probably be opened at much greater ranges.

[138] Elphinstone, 'Notes' 1916.
[139] Oscar Parkes, *British Battleships* (London, reprinted 1990) pp.521, 528 and 538: 'Practices of Ships fitted with Director firing', 15 May 1914 in 'Important Questions dealt with by DNO. Copies, precis, &c. Vol. III, 1914', AL. *Sea Heritage*, pp.74-5.
[140] C.-in-C. Home Fleet G.0360/14, 'Practices of Ships fitted with Director Firing', 15 May 1914 and '"Colossus" Report on Rangefinders', 20 May 1914 in IQ/DNO, Vol.III, 1914 (*op. cit.*).

Ships adopting R.F. control were warned that they 'must be prepared...to revert to the alternative system *i.e. maintaining the Range by means of the Rate*'.[141]

Rangefinder control was more suited to peacetime practice ranges than the much greater ranges experienced during the War.

> The method...appears most suitable when concentration renders spotting unreliable, or frequent alterations of course and speed of the enemy makes rate-keeping very hard. But it should be avoided at very long range, and cannot be used unless the conditions admit of good range-taking.[142]

Nonetheless, it firmly established the advantages of being able to plot as many ranges as possible from all the rangefinders that could range on the target. Thus, during 1913, there had been an important change of emphasis, from the automatic plotting of the ranges from one rangefinder to the need (by whatever means) to plot ranges from a number of rangefinders at once. In fact, this had already been anticipated by Dreyer in February 1913; for any future supply of Dreyer tables, he expected that:

> The Time and Range plot will have arrangements provided to enable the results of several Range Finders to be plotted.[143]

However, he can have had little opportunity to influence subsequent developments once *Amphion* commissioned on 2 April. By June (in the month when he was promoted to Captain) his ship came, and remained, top in the Gunlayer's Test and, subsequently, she was first in her category at Battle Practice. Further advancement soon followed, when, on 27 October, he was appointed Flag Captain to Rear-Admiral Sir Robert Arbuthnot second-in-command of the 2BS;[144] thus he arrived too late to have had any influence on the *Home Fleet Order* of 5 November. His new ship was the *Orion*; the Navy, while watching the rapid rise of Jellicoe's protégé, must have derived no little amusement from Dreyer's appointment to the only ship with a TS entirely equipped by the Argo Company.[145]

DREYER TABLES MARK IV AND IV*

Just before he formally assumed command of *Amphion*, Dreyer submitted to the DNO 'some diagrammatic sketches and a description of some additions which if made to

[141] *Home Fleet, Fire Control*, 1913 (*op. cit.*) p.3 and Enclosure No. I, 'Remarks on Rangefinder Control'.
[142] Admiralty, Gunnery Branch, *Manual of Gunnery (Vol.III) for His Majesty's Fleet, 1915*, pp.17-8, AL.
[143] Addendum (February 1913) in *Technical Comparison*, pp. 47-8.
[144] *Sea Heritage*, pp.72-5. Dreyer to Jellicoe, 14 June 1913 in DRYR 4/3.
[145] *Orion* does not appear in the list of 10 February 1916 in the Dreyer Papers, which suggests that it still relied on the Argo rate plotter. The *Handbook 1918* lists *Orion* as having a Dreyer Table Mark II; presumably by then it had been given Dreyer-type range and bearing plots

my fire control apparatus would make it more automatic than at present' (Plate 45). He proposed that changes in the Dumaresq range-rate and speed-across should be detected and transmitted by commutator switches to step-by-step receiver motors. The range-rate motor was to set the rate of the range-clock directly. The speed-across motor drove the cone of a cone-and-roller variable speed drive. The roller was somehow positioned by the range-clock, while its shaft set the rate of the bearing clock by means of a third commutator and motor.[146] His scheme resembled the Argo Clock Mark III in using two coupled variable-speed drives to generate bearings, but, by retaining the clock set for bearing-rate (and, probably, in also striving to avoid infringing the Argo patent), Dreyer rearranged the elements into a mathematical nonsense (XVIII-14). It must be doubted, therefore, whether he understood properly how the Argo design worked.

Although the automatic design as finally adopted was entirely different, this proposal did introduce the principle that the Dumaresq rates could be transferred to the clocks electrically. However, it is unlikely that any step-by-step motor could have generated sufficient torque to move the rollers of the range and bearing clocks. Dreyer himself apparently recognised none of these problems and, in February 1913, declared that, for future supplies of the tables:

> ...the following additional parts have been designed and will probably be included. ...Automatic attachments, which...will automatically keep the Dumaresq adjusted for the Bearing of the Enemy, and also automatically keep the pointer of the roller of the Range Clock in line with the bows of the enemy ship...

His list of new parts (XIII-15) ended with the arrangements 'to enable the results of several Range Finders to be plotted'.[147] In reality, it is unlikely that the design of any of these additions had yet been taken in hand by Elliott Brothers. With the supply for the *King George V* class and *Queen Mary* already settled, no more tables were now required until the completion of the *Iron Duke* class and *Tiger* in 1914. Thus priority could be given to the provision of local control tables for use in turrets. The question had been raised in May 1912 and, in August, Dreyer was instructed to work with Elliott Brothers on a suitable design.[148] A prototype was being made at the end of 1912 and, by March 1914, was installed in a turret of *Queen Mary*. By that time, the first Mark IV Table, for *Iron Duke*, was

[146] Dreyer to DNO, 19 December 1912 in T.173/91 Part III.
[147] *Technical Comparison*, pp. 47-8.
[148] DNO and ITP, 'Local Control in Turrets', 24 May 1912 and Secretary of the Admiralty to C.-in-C. Home Fleets etc. 7 August 1912 in IQ/DNO, Vol.I, 1912, pp.248-255. See also DNO's minutes of 30 July and 3 August 1914 in IQ/DNO, Vol. III, 1914.

already under construction, though a letter from Keith Elphinstone dated 14 March gives the impression that many details remained undecided.[149] Nonetheless, by 6 July, the new table had been tested by the DNO's representative and it was decided to order four more sets; it was expected that the prototype would be placed on board *Iron Duke* in mid-August:[150] though this was no doubt delayed by the flagship's departure for Scapa Flow. The next three Mark IV tables were fitted in *Tiger*, *Benbow* and *Emperor of India*, all completed in October and November. The fourth ship of the *Iron Duke* class, *Marlborough*, was completed in June 1914 and never did receive a Mark IV table; the final unit was supplied instead to *Queen Elizabeth* (commissioned in December, 1914).[151]

The first Mark IV* was already aboard *Warspite* when she ran her gun trials in April 1915:[152] and thereafter until after the completion of *Courageous* and *Glorious* in January 1917, this was the standard model. The only major difference between the two marks was in the width of their range plots. As delivered, the Mark IV plotted ranges from 2,000 to 17,000 yards, whereas the maximum range for the Mark IV* was 20,000 yards.[153] The well-illustrated 1918 *Handbook* has been used by several authors as the principal source for design details.[154] However, it was not promulgated until June 1918, and incorporates many later improvements. Fortunately, the cyclostyled handbook delivered in May 1916 with *Royal Oak's* Mark IV* table survives in the *Excellent* Historical Library; its text and illustrations were in turn based on material first prepared for the Mark IV Tables.[155] The following account attempts to deduce from these and the few other available sources the main features of the automatic Dreyer tables as used at Jutland, before describing the more important subsequent developments.

[149] *Technical Comparison*, p.47 (1912 Addendum): DofC to Elphinstone, 10 March and Elphinstone to Dof C, 14 March 1914, sheet 3 in 'Fire Control Various Patents'.
[150] 'Dreyer's Fire Control Apparatus', 6 July and '"Iron Duke" Gunnery and Torpedo Exercise Programme' 11 July 1914 in IQ/DNO, Vol.III, 1914, pp.617 and 587.
[151] Parkes, *British Battleships* (*op. cit.*) pp.545, 551 and 577 for completion dates. 'Ships...Dreyer's Fire Control...fitted' (1916). *Handbook 1918*, p.3.
[152] 'Report on *Warspite's* Gun Trials', 15 April 1915 in Ships' Cover 294A/58a, *Queen Elizabeth* Class, NMM.
[153] *Handbook 1918*, pp.3 and 22 (the range scale was 400 yards per inch and the speed of paper 2 inches per minute.) *Technical History*, p.27. 'Ships...Dreyer's Fire Control...fitted' (1916). The *Handbook 1918* also list *Lion* and *Princess Royal* as having Mark IV* Tables; the dates when their Mark IIIs were replaced are not known but were probably in 1917: see XVIII-18.
[154] *IDNS*, pp.218-220 and Plates 7 and 8. Peter Padfield, *Guns at Sea* (London, 1974) pp.224-7 and 231. Guy Hartcup, *The War of Invention* (London, 1988) pp.12-3. Schleihauf, 'Dumaresq and Dreyer'.
[155] Elliott Brothers, London, 'Captain F C Dreyer's Fire Control Apparatus Mark IV*. As fitted in HMS Royal Oak', May 1916, *Excellent* Historical Library. Many of the figures are captioned 'Captain Dreyer's System Mark IV. HM Ships Iron Duke & Class and Tiger' and are dated from August to December 1914.

BEARING PLOTS

As originally fitted, the bearing plots of the Mark IV and IV* tables were similar to those already described for the Mark III (the design shown in the 1918 *Handbook* was introduced much later). A second graduated drum was added to convert the bearing-rate into the component of the Gun Deflection due to speed-across.[156] The principal change was in the source of bearings. Beginning with the *Iron Duke* class and *Tiger*, all heavy ships were provided with a squat, armoured Gun Control Tower (GCT) protruding above the Conning Tower. In the 13.5-inch ships, a revolving armoured hood covered the 9-foot rangefinder on an Argo mounting. In contrast, all 15-inch ships were completed with a much larger armoured hood accommodating both a director sight and a 15-foot rangefinder on a Barr and Stroud mounting.[157] In *Iron Duke* and later ships, the tables received target bearings not from the rangefinder but from a special Dumaresq, the Mark VII*, of which two were installed, one on each side of the GCT (except, it seems, in *Tiger*). By 1915, each Dumaresq had been coupled to an Evershed binocular holder; thus the same sighting device was used both as a target indicator and source of bearings. These were transmitted by a commutator in the Dumaresq, as bearings relative to ship's head, to a large step-by-step receiver motor in the Dreyer Table. This motor was coupled to a differential, the other side of which was connected to the motor relay controlled by the gyro compass; thus the differential output gave the target compass bearing and could rotate the screw positioning the pencil of the bearing plot.

Like the Argo mounting, the Mark VII* Dumaresq transmitted bearings in relatively coarse steps of ¼°.[158] However, the hunting associated with the relay supplied with the Anschütz gyro compass appears to have had a more serious impact; Midshipman Patrick Blackett of *Barham* found that:

[156] *ibid.* pp.14-5, 44-9 and Figs. XII and XIII.
[157] John Brooks, 'The Mast and Funnel Question' in John Roberts (ed.) *Warship 1995* (London, 1995) pp.50-1. Admiralty to C.-in-C. Home Fleets and Admiral Superintendent, Portsmouth, both 21 October 1913 in Ships' Cover 268A/8, *Iron Duke* Class, NMM.
[158] '*Warspite's* Gun Trials' (*op. cit.*). Elphinstone, 'Dumaresq Instruments Designs & Patents. Notes as to History', 31 January 1916 in ADM 1/8464/181. Dreyer (who was Captain of *Iron Duke*) described the binoculars to the RCAI: T.173/547 Part 17, p.31. 'Dreyer's Apparatus Mark IV*' 1916 (*op. cit.*), pp. 44-46, 50A-51A and Figs. XIII and XIX dated December 1914; despite the date of the figures, *Tiger* at Jutland, 'not having the Mark VII [*sic*] Dumaresq', could not make bearing plots of any value: Gunnery Report, 30 October 1916 in 'Jutland Despatches', ADM 116/1487. For the Dumaresq in *Valiant's* GCT, see Peter Liddle, *The Sailor's War 1914-1918* (Poole, 1985) p.108.

> The chief disadvantage...lies in the fact that the gear actually operating the bearing plot is large and heavy - necessitating a powerful "relay-system" from the Gyro[-receiver] to eliminate yaw...."hunting" takes place, which tends to render a plot of little value.[159]

By 1916, existing Anschütz installations were being replaced,[160] while Elphinstone was referring to a new form of relay control switch which 'has the advantage of working with extreme accuracy'. This switch, which was incorporated in a mechanical differential, is the only one described in the surviving handbooks;[161] it appears that, when the Sperry receivers were first introduced, the opportunity was taken to develop a new design with much less tendency to hunt. However, it is likely that a number of ships, *Barham* included, fought at Jutland with the older type of compass and relay.[162]

Before the battle, some ships may have taken up a suggestion by *Queen Elizabeth* to increase the movement of the bearing pencil for each degree change in bearing; this had been prompted by 'the small bearing rates involved by the increase of range at which actions are likely to be fought'.[163]

RANGE PLOTS

In March 1914, it was intended that the Mark IV Table should plot the ranges from several rangefinders using a pneumatic device invented by Lieutenant Macnamara; Elphinstone was then working on a scheme to prevent the 'recording points' from jamming should two records be made simultaneously at the same position.[164] The whole device must have been very complex,[165] and, in May 1914, the prototype was ordered of a much simpler, keyboard-operated device designed by Commander J Brownrigg. On 6 July, it had been decided to inform Elliotts that no order would be placed for the

[159] Blackett, 'Rate of Change of Bearing Instrument' (*op. cit.*). *Barham* had a Mark IV* table. For the proposed instrument, see John Brooks, 'Midshipman Blackett and the Secret Gadget', Centenary Conference, 'Patrick Blackett: Lord, Professor and Lieutenant, Royal Navy', Cambridge, 24 September 1998.

[160] Fanning, *Steady As She Goes*, p.195. *Technical History*, p20.

[161] Elphinstone, 'Notes', 1916, p.7 cites 'Dreyer's Apparatus Mark IV*' 1916, Fig.XVII. *Handbook 1918*, p.64 and Plate 28.

[162] By October 1916, *Barham* had a Sperry gyro compass: Fanning, *Steady As She Goes*, p.196. Blackett's diary (*op. cit.*) does not mention the change, but there was ample opportunity during the ship's repair at Devonport after Jutland: entries for 5 June and 3 July 1916.

[163] *Technical History*, 1919, p.27.

[164] Elphinstone to Dof C, 1914, sheet 6.

[165] Compare with the equivalent unit described in Admiralty, Gunnery Branch, *Handbook for Admiralty Fire Control Table Mark I*, September 1927, pp.67-76 and plate 7, ADM 186/273-4.

Macnamara plotter[166] and, on 7 August (after favourable reports had been obtained verbally), that 9 more Brownrigg keyboards should be ordered immediately.

> At present the plotting tables in H.M. Ships are provided with no means of plotting a number of rangefinders and the need for some such instrument is urgently required.[167]

Subsequently, the Brownrigg device became the standard fitting until after Jutland. It had four rows of ten keys, each key representing a step in range of 50 yards. The range-bar was notched so that the carriage for the keys could be located quickly and accurately in 1000 yard increments. Once positioned, the keys could be used to perforate the paper for ranges from 1000 yards below the nominal position to 950 yards above it. In 15-inch ships, the Brownrigg keyboard was the only means of plotting the ranges displayed on the Barr and Stroud range receivers. Furthermore, drawings dating from 1914 suggest that the other Mark IV tables were not equipped for automatic plotting of the Argo ranges ;[168] thus, in the Dreyer Tables, automatic range plotting remained a feature only of the early Tables Mark II and III (XVIII-16).

By early 1915, the Battles of the Falkland Islands and the Dogger Bank had shown that, in good visibility, firing could commence at the limits of the gun range. In August, it was decided to fit the range scales of the Mark IV Table with sliding numeral strips so that, through small windows cut in the scales, they could be read either from 2,000 to 17,000 yards or from 10,000 to 25,000 yards. This required the fitting of a 'pedalling clutch' by which the clock-range pencil could be shifted by 8,000 yards without changing the gun-range. Similar modifications extended the maximum ranges of the Marks III and IV* to 24,400 yards and 28,000 yards respectively.[169]

THE ELECTRICAL DUMARESQ AND CLOCKS

Other than the principle of electrical transfer of rates, Elphinstone's design for the Electrical Dumaresq and clocks for the Mark IV Table owed nothing to Dreyer's erroneous proposal of December 1912. On the Dumaresq (which was entirely redesigned)

[166] 'Dreyer Fire Control Apparatus', 6 July 1914 in IQ/DNO, Vol.III 1914, p.617

[167] 'Tender for Brownrigg Plotters', 7 August 1914 in IQ/DNO, Vol.III 1914, p.433. The quantity ordered was insufficient for the existing 5 Mark II and 5 Mark III tables as well as the 4 remaining Mark IVs, but, in view of the urgency expressed, all were probably fitted eventually.

[168] 'Dreyer's Apparatus Mark IV*' 1916, p.33 and Figs. I and V. The turret table appears to have been the first to plot by perforating the paper from below; Elphinstone to DofC, 1914, p.3; *Handbook 1918*, pp.81-2 and Plates 36-7.

[169] *Technical History*, 1919, p.27, though this states that the Mark IV's maximum range was 27,000 yards. The ranges quoted are from the *Handbook 1918*, pp.17 and 22. Neither source mentions a similar modification to the Mark II tables.

the enemy bow pointer was replaced by a downward-extending 'contact stem' pressing upon a circular 'contact plate' (Plate 46). The contacts determined the energising of relays which controlled a pair of 20-volt motors; their joint action enabled the contact plate to follow automatically any change in the position of the contact stem (Plate 47); this plate soon became known as the 'poached egg...which insists on impaling itself on the fork'.[170] Two pairs of brackets, protruding through slots in the Dumaresq's fixed dial, positioned the contact plate. One pair was coupled directly to the roller of the range-clock, while the second pair was linked to the change-of-bearing (C. B.) gear which positioned the roller of the bearing-clock; thus Elphinstone had devised a novel, dual-axis 'hunter' which enabled the rates of both clocks to follow the indications of the Dumaresq automatically.[171]

As in the Mark III, the clocks were of the conventional disc-and-roller pattern, the cast-iron discs being driven by the main speed-regulated motor (Plate 48). There were substantial mechanical loads connected to both clock roller shafts: but, since the 20V motors could supply ample torque to move the rollers against friction with the disc, the assembly force could be made large enough to minimise slippage. In 1918, the standard test for the Tables Mark IV and IV* was to simulate two 28-knot ships on opposite courses passing each other at a minimum range of 7,000 yards; it was expected that, after a 12-minute run, the range would return to its initial starting value (13,200 yards) without an appreciable error in range or bearing. Since this test produced a large change of range-rate, it would have resulted in a substantial range lag if the assembly force had been insufficient.

Automatic working also depended on the C.B. gear (Plate 48) continuously dividing speed-across by range to generate bearing-rate. For this purpose, Elphinstone used a proportional lever; one end was coupled directly to the speed-across motor while the other end was linked to the bearing-clock roller. The pivot between them was positioned by a spiral cam which, through a connection to the clock-range screw, was rotated in proportion to change of range.[172] This gear does bear some resemblance to the

[170] Dreyer before RCAI, T.173/547 Part 16, p.84. See also Tower before RCAI, T.173/547 Part 12, p.103.
[171] 'A certain amount of backlash is necessary to make the hunt dead-beat': 'Pamphlet on the Mark IV* Dreyer Table 1930', p.14 in 'Guard Book for Pamphlets on Dreyer Tables', AL. This was probably obtained by making the diameter of the plunger contacts slightly less than the width of the insulating circle on the contact plate.
[172] 'Dreyer's Apparatus Mark IV*', 1916, pp.25-8 and 36 and Fig.IV and VII. *Handbook 1918*, pp.51-5, 61 and 87 and Plates 22 and 24-7.

corresponding mechanism patented by Argo for their Mark V clock, although their fixed pivot was at one end of the lever. Hence the spiral cams were cut to different functions of the range (XIII-16). Furthermore, Elphinstone first proposed 'a system of proportional levers' in March 1914. This was well before the date of acceptance and earliest publication of Argo patent 16,373/1913 on 16 July 1914, by which time the prototype Mark IV Table had already been under test. By 1916, Elphinstone was aware that Argo were using a device 'on lines somewhat similar to that [used in the] Tables, Mark IV and IV*'; though he described his design (and, by implication, Isherwood's) as 'a special application of a known mechanical method'.[173] While Isherwood was first to use a lever and cam to generate bearing-rate, the available evidence[174] indicates that Elphinstone was unaware of this when, independently, he decided to use the same well-known principle, though in a significantly different configuration, for his own change-of-bearing gear.

JUTLAND TO THE ARMISTICE

> In July 1916 an experimental typewriter was tried for identifying the ranges from each particular rangefinder....Supply of these to existing tables was made in 1917.

Thus the Brownrigg keyboard was replaced by the typewriter, which was the only means of plotting described in the 1918 *Handbook* for all tables, including the Mark III. The new typewriter provided nine characters (Ţ, C, R, •, Y, X, Q, B and A), thereby enabling 'the plotting officer to obtain an idea of the relative reliance to be placed on each...rangefinder'.[175] Thus the device was a further, relatively late step in the evolution of manual plotting; it had nothing to do with the development of the Original Table, which plotted automatically.[176]

Dreyer returned to the Admiralty as DNO on 1 March 1917. He himself was mainly preoccupied by the development and supply of new AP shell, but he also 'set up a Fire Control Staff, which included scientists, and did valuable work'. Despite his duties in the Grand Fleet (he became Flag Captain to Jellicoe in *Iron Duke* on 24 October 1915),[177] Dreyer had continued to invent and, in 1916, proposed a 'Wind Dumaresq for the Dreyer Fire Control Table'.[178]

[173] Elphinstone to DofC, 1916 and 'Notes', 1916, p.7.
[174] For further details, see XVIII-17.
[175] *Technical History*, 1919, p.27. *Handbook 1918*, p.29 and Plate 12.
[176] cf. *IDNS*, pp.218-9.
[177] *Sea Heritage*, pp.96 and 234-5.
[178] Undated list (but after 12 December 1923) of 'Rear Admiral Dreyer's Inventions' in DRYR 2/1; see also

> ...in the first half of 1917 complete wind Dumaresqs were supplied for use with the Dreyer table, together with deflection totalisers, by means of which Dumaresq deflection corrected for range, deflection due to wind, uncorrected drift and spotting corrections, are superimposed on each other and transmitted mechanically to a position near the master deflection-transmitter to the guns.[179]

These additions were probably designed under Admiralty auspices: but the gunnery officers of the Grand Fleet were also developing their own ideas.

> In August 1917, after various experiments by individual ships, it was determined that a gun-range pencil must be provided on the range-plot. This pencil shows continuously the actual gun-range in use, and a comparison between gun-range and clock-range is valuable in keeping the range.

The screws required to work these pencils are shown in some of the plates for the 1918 *Handbook* (Plate 49), so any necessary new fittings were probably being supplied by the Admiralty when the handbook was promulgated on 25 June 1918,[180] five days after Dreyer had been succeeded as DNO by Captain Henry R Crooke; Dreyer himself became Director of Naval Artillery and Torpedoes with responsibility for the Gunnery and Torpedo Division of the Naval Staff.[181]

In contrast to the evident agreement reached over the gun-range pencil, the Admiralty's attempts to develop an improved bearing plot were overtaken by much more radical ideas originated in the Grand Fleet.

> ...until the Mark V. table for "Ramillies"...bearings were transmitted in ¼° steps. In the Mark V...these were reduced to 4-minute steps....This necessitated a special form of bearing transmitter which was manufactured by Messrs. Elliott. This table was erected in "Ramillies" in July 1917. Orders were placed for bearing transmitters and for improved bearing plotting gear...for all capital ships, but owing to the introduction of the Gyro Director training gear, which embodied this improvement, but used the gun director as the bearing transmitter, this order was cancelled.

This 'GDT' gear had been developed initially by a Committee of the Grand Fleet, which, after the inconclusive action of 17 November 1917, had been established to evolve:

> ...an instrument, which, by a combination of the gun-director, Gyro compass, and the bearing clock of the Dreyer table, enabled the Director to be kept on for direction when the enemy was hidden, provided that he had been effectively engaged before his disappearance.
>
> ....
>
> ....in July 1918 a complete instrument was supplied by H.M.S. Excellent to H.M.S.

---

the *Handbook of the Dreyer Tactical Appliances 1915* in DRYR 1/3.

[179] *Technical History*, 1919, p.27. The Wind Dumaresq, when set with own speed and course and true wind and direction, indicated the components of 'wind-you-feel' along and across the line of bearing

[180] *ibid. Handbook* 1918, p.2. See XVIII-16 for possible reuse of the rangefinder screw for gun-range on Mark III tables.

[181] *Navy Lists. Sea Heritage*, p.236. O Murray, memorandum 27 June 1918 in 'Re-organisation of Naval Staff Division 1917-1921', ADM 116/1803.

> Emperor of India for trial. In September, provisional approval was obtained to proceed with designs for this gear in which certain parts already in service, and other gear which was previously on order for the improvement of the bearing plot of the Dreyer table, were to be embodied. Approval to place the order for 24 capital ships with Messrs. Elliott, who had prepared the designs, were given in January 1919.[182]

However, the complete GDT prototype had not yet been built when the 1918 *Handbook* was being prepared, which explains why it described the improved bearing plot as a standard-pattern fitting on all tables. In fact, the cancellation of the improved bearing plotting gear meant that, apart from the prototype supplied to *Ramillies* and, perhaps, a few early production models,[183] most Dreyer bearing plots ended the War still receiving bearings in ¼° steps.[184]

DREYER TABLE MARK I

In February 1916, the Ordnance Coucil awarded Dreyer £5,000 for his contributions to fire control. The list of the 'Ships in which Dreyer's Fire Control is fitted or is being fitted', drawn up when Dreyer applied for his award, included the following:

> <u>MARK I (Simple Mechanical Table...)</u>
>
> Marlborough
> Dreadnought
> Bellerophon
> Vanguard
>
> Superb
> St. Vincent
> Collingwood
> Temeraire
> Neptune
> Colossus
> New Zealand
> Australia
> Erin
> Inflexible.[185]

[182] *Technical History*, 1919, pp.28-9.
[183] Sufficient units were available to be included in the photographs of the various marks of table included in the 1918 *Handbook*; see for example *IDNS*, Plates 7 and 8.
[184] After the War, GDT gear was fitted to all Mark IV and Mark IV* tables and to the table in *Ramillies*; all were then designated Mark IV*. Mark V was reserved for the table in *Hood*, which was much more elaborate. 'Pamphlet on the Mark IV* Dreyer Table 1930' and 'Pamphlet on the Mark V Dreyer Table 1930' in 'Guard Book for Pamphlets on Dreyer Tables', AL.
[185] With 'Extract from Recommendations of the Admiralty Members of the Ordnance Council at a Meeting 10.2.16 concerning Dreyer's award' in DRYR 2/1. See also Dreyer to Field, 1923.

This is the first mention of such a table since the Mark I Board of 1911. Notice the curious order and the gap after the first four ships; also, that three battlecruisers - *Invincible*, *Indomitable* and *Indefatigable* - do not appear, nor were they listed under any other mark of Dreyer Table. In the equivalent list from the 1918 *Handbook*, *Vanguard* (sunk by an internal explosion) is missing. *Agincourt* had now received a Mark I table: while a Mark I had also replaced the Original Table in *Hercules*. As would be expected, *Invincible* and *Indefatigable* are not listed, but, while *Inflexible*, *Australia* and *New Zealand* remain, *Indomitable* still does not appear.[186]

A handbook for the Mark I was published in 1916[187] but, since a copy has not been found, it is necessary to rely mainly on the description in the 1918 *Handbook*. The table was built around the Mark VI* Dumaresq, for which the first production order was placed on 11 October 1914. Like ordinary Dumaresqs, the Mark VI* had a fixed fore-and-aft bar and a rotating dial; when built into the Mark I Table, a slot, running most of the length of the target-indicating arrow; contained a small pointer. Since this was coupled through a flexible shaft to a handle which also set the clock-rate, it was necessary only to follow the rate indications of the Dumaresq's enemy bow with the pointer.[188]

The range-plot was similar to the other Dreyer tables, except that the paper was moved only by hand. However, it extended across the full width of the Mark I and, from the start, was capable of plotting up to 20,000 yards (later extended to 28,000 yards), just like the Mark IV* Table, first fitted in *Warspite* in the Spring of 1915.[189] At first, the Mark I range-plot probably had a Brownrigg keyboard until that was replaced by the standard typewriter.[190] Range was kept by a Vickers clock on the same lines as proposed by Dreyer for the Mark I Board. Thus the table was entirely mechanical (Plate 50). The 1918 *Handbook* shows a standard-pattern bearing plot (of the type which was cancelled) and a deflection totaliser (as supplied in 1917) squeezed in next to the Dumaresq.[191] There could never have been space for the old style of bearing plot and it is unlikely that the Mark I

[186] *Handbook 1918*, p.3.
[187] *Technical History*, 1919, p.28.
[188] Elphinstone, 'Dumaresq History', 1916 (*op. cit.*) p.11; this does not mention the Mark I Table. *Handbook 1918*, pp.13 and 46 and Plates 3, 21 and 22.
[189] Because the clock-tuning and spotting differential gearboxes were located together, the Mark I had an unusually compact arrangement for the pedalling clutch, a feature not introduced on other tables until the Autumn of 1915. This may indicate that the design was completed in the second half of the year.
[190] Although a gun-range screw is shown in the diagrams of the 1918 *Handbook*, it cannot be made out in the photograph. There are no signs that the Mark I was ever equipped to plot Argo ranges automatically.
[191] *Handbook 1918*, pp.13 and 29 and Plates 3, 21-2 and 39.

Tables were given any priority in the distribution of the few new-style standard plotters that may have been completed. Without a bearing plot, the deflection totaliser would have been much less useful. It must be assumed that, until the War's end, ships with Mark I Tables plotted bearings (if at all) with Admiralty manual plotters, and calculated deflection by hand.

All the evidence given here suggests that deliveries of the Mark I Tables began some time in 1915. This dating is supported by the schedule of deliveries for the Mark IV*s, which shows (XVIII-18) that only two automatic tables were required for ships completing between April 1915 and January 1916. It may be conjectured that the list from February 1916 represents the planned installation schedule for Mark I Tables, and that only the first four ships had then been fitted.[192] There is no definite information on the extent of progress by the time of Jutland, although subsequent reports and memoirs (quoted in XVIII-19) indicate that *Bellerophon* had received a Dreyer table, but that *Invincible*, *Indomitable*, *New Zealand* and *Erin* had not. Thus, it is almost certain that, at the Falkland Islands and the Dogger Bank, none of the 12-inch battlecruisers present had Dreyer tables. It is also quite possible that, at Jutland, all the ships of both the Second and Third Battle Cruiser Squadrons had to rely on the pre-War system based on the Mark VI Dumaresq, Vickers clock and manual plotting.

The Mark I Table was followed by the short-lived Mark I*, which was very similar apart from the addition of a coupling between the Mark VI* Dumaresq and a gyro-compass relay. This in turn led to the Mark III*, which became the standard table for use in cruisers. It replaced the Vickers clock with an electric clock similar to that in the Turret Tables. As described in the 1918 *Handbook*, it was originally designed to use the cancelled bearing plot, but the design was subsequently altered to incorporate the GDT gear (Plate 51). This in turn required a bearing clock, which was set for rate by hand using values read off a graduated drum.[193] Thus, in its use of a gyro-compass connection to the Dumaresq, bearing plotting (in the straight-line form introduced by the GDT) and hand-set rates on the bearing clock, the Mark III* was also a direct descendent of the earlier Mark III.

[192] As would be expected, *Marlborough*, the only 13.5-inch ship without a fire-control table, is at the head of the list. However, there is no apparent reason for the remaining order.
[193] The post-War Dreyer tables are described in more detail in Appendix XXIII.

CONSTRUCTION

Especially in comparison with the enclosed and largely maintenance-free designs of the Argo Company, the Dreyer tables had a certain Heath-Robinson character.[194] Their mechanical construction was much less sophisticated. Gear wheels were held on their shafts by tapered pins which were hand-made, non-interchangeable and could be shaken out by prolonged firing.[195] Chain drives and flexible shafts were liable to wear, which caused backlash; although not usually serious,[196] in the change-of-bearing gear the effects were magnified at low ranges, to the extent that accurate results could not be obtained below 5,000 yards. Regular lubrication, especially of the parts driven by the variable speed drives, was essential although, because of the open construction, the oil attracted dust, so frequent cleaning was also a necessity. In the clock mechanisms, the cast iron clock discs had to be kept completely free of oil.[197] Also, it was vital to move the hardened steel wheels only when the discs were rotating, otherwise the wheels developed flats and had to be replaced. The rough surface of the cast iron appears to have been well chosen to maximise friction: but it may have been more liable than a hardened steel disc to develop a recess at its centre.

> In this event, the recess should be removed by turning up the disc in a lathe.[198]

Electric relays might stick, but switches were provided to isolate the fault and permit hand-setting of rates.[199]

On the other hand, as Dreyer and Usborne emphasised in 1913:

> ...the whole apparatus is so simple that it can easily be repaired...with the resources of the ship.[200]

Further, during the War, it was also possible for ships' gunnery officers to modify their tables in the course of developing new techniques, for example in concentration firing and gyro director training.[201] It is very difficult to imagine how the Argo instruments, the

[194] Schleihauf, 'Dumaresq and Dreyer' (*op. cit.*).
[195] *Handbook 1918*, p.10. 311. 'Remarks on the Action of 17th November 1917' in *Grand Fleet Gunnery and Torpedo Orders*, p.196, ADM 137/293.
[196] The maximum permissible accumulated backlash in the Mark V table from the tuning and spotting handles to the master transmitter was no more than 75 yards: Schleihauf, 'Dumaresq and Dreyer'.
[197] 'Pamphlet on Mark IV* 1930' (*op. cit.*) pp.47, 50-2 and 55.
[198] *ibid.* p.14. The clock discs rotated at 15 revolutions per minute.
[199] 'Dreyer's Apparatus Mark IV*', May 1916, Additions to Book
[200] *Technical Comparison*, p.56.
[201] 'Third Interim Report' in Admiralty, Gunnery Branch, *Reports of the Grand Fleet Dreyer Table Committee 1918-1919*, 1919, pp.5-11, ADM 186/241.

true-course plotter in particular, could have been modified to perform even a few of the functions which had been added to the Dreyer Tables by the end of the War: and, if such changes had been possible, they could only have implemented at the works of the already overstretched Thomas Cooke and Sons.

The Dreyer Tables certainly needed careful maintenance and well-trained operators, which the Royal Navy could normally be expected to provide. They may also appear somewhat crude to modern eyes, though that is neither here nor there. The vital question, which can now be addressed in the next chapter, is whether, in the conditions experienced during the Run to the South, their functional characteristics made them less capable than the Argo system of accurately predicting the gun range in battle.

Plates for Chapter 5

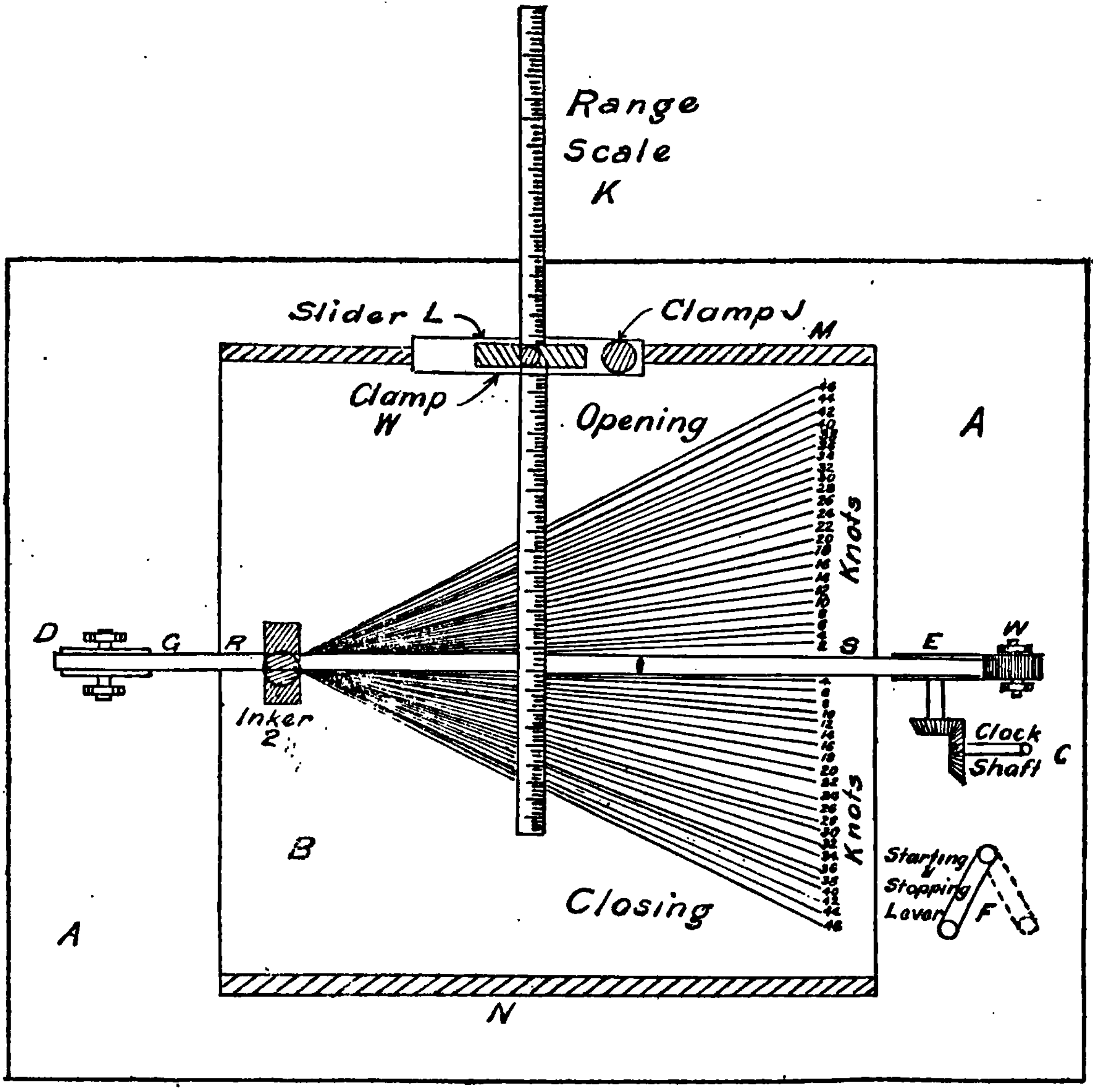


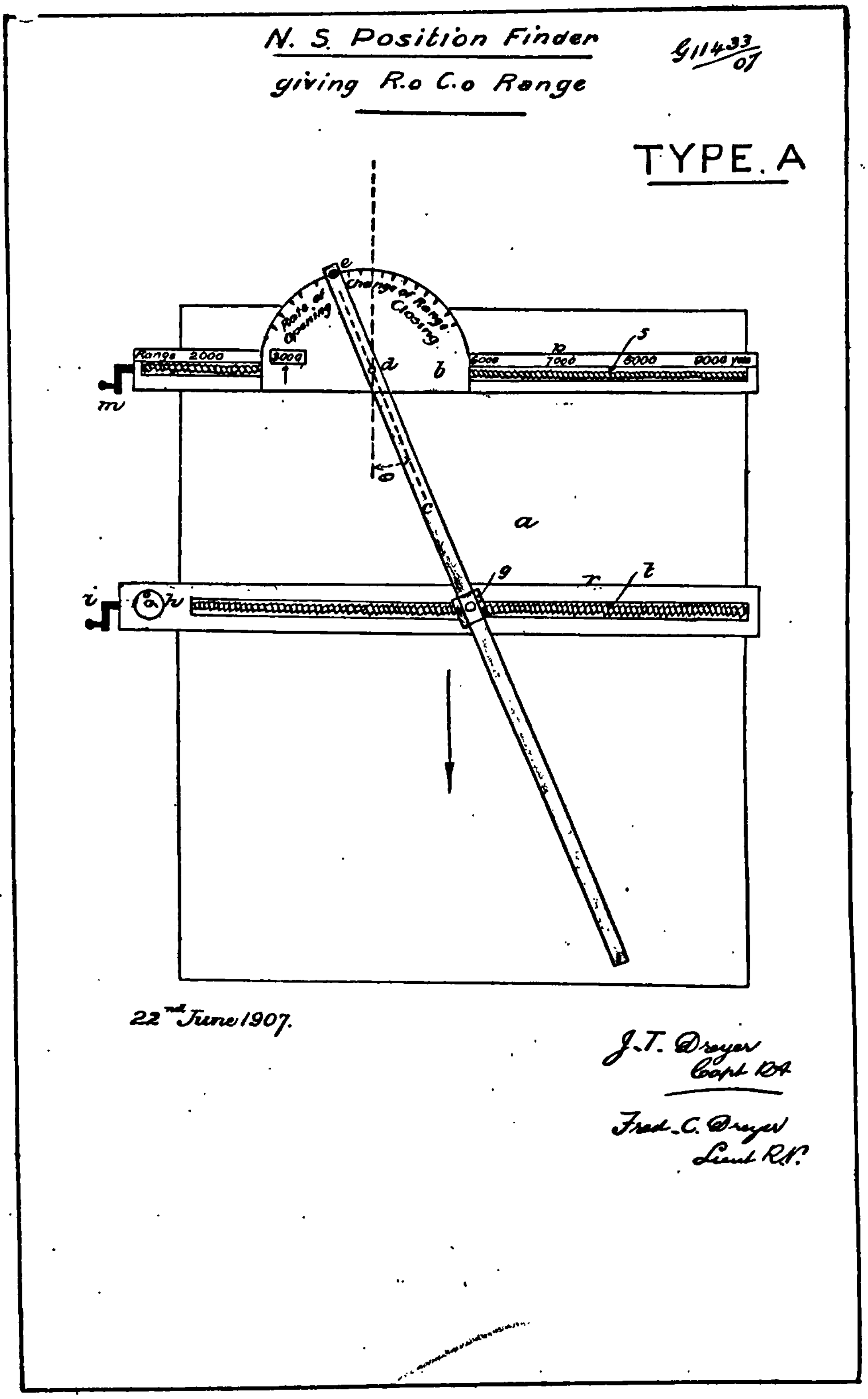
Fig 1
(Diagrammatic Sketch)

30. Dreyer's Rate of Change Calculator (December 1906)

The narrow paper tape was driven at a constant speed by clockwork across the centre of the board. The ruler graduated in ranges was held in a slider, which could move along the length of the tape; the ruler could also slide at right angles to the tape.

When a range was received, the tape was marked by an 'inker' and the ruler set so that the tape mark indicated the range received. The ruler was kept over the mark until another range was received. This range on the ruler would correspond with the one of the range rate lines (marked in knots) radiating from the ink marker; thus the rate could be read off without calculation.

Dreyer, 'Change of Range', 10 December 1906 in DRYR 2/1 and T.173/91 Part III.

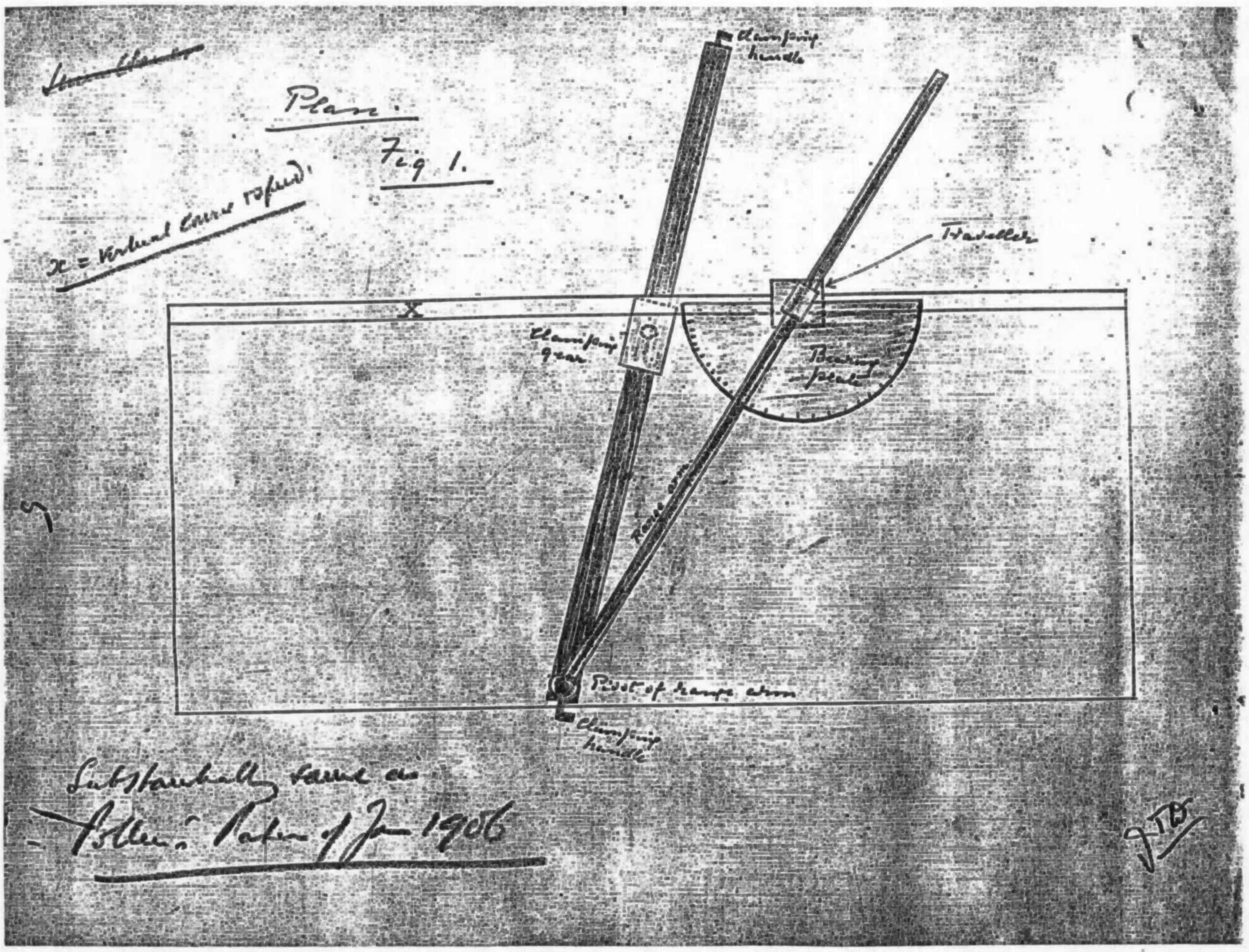


31. The Dreyers' Position Finder for Rate of Change of Range (1907)

The broad strip of paper moved at constant speed: the strip being as wide as the range scale on the fixed, upper bridge. Each range was marked on the paper by a pencil in the 'traveller' moving against this range scale; the traveller and pencil could be actuated electrically from the rangefinder.

Each range mark was followed by the microscope on the traveller carried by the lower, movable bridge. As soon as the next range was plotted, the bar linking pencil and follower-microscope indicated a momentary range-rate on the semi-circular scale.

F C and J T Dreyer, 'Position Finder for determining Rate of Change of Range', July 1907 in T.173/91 Part III.



32. Dreyer Virtual Course Instrument (1908)

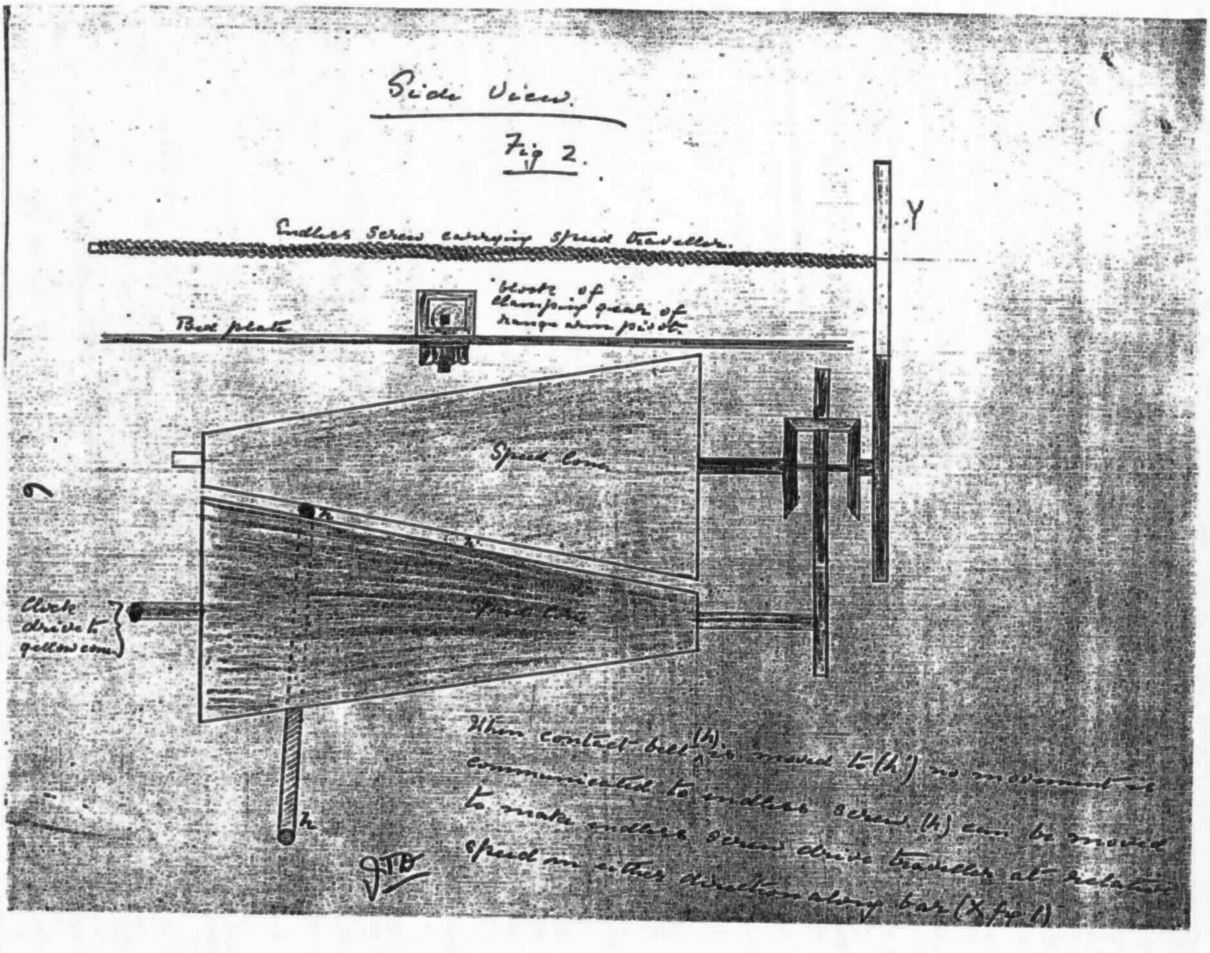
The traveller was propelled by a long screw at a speed proportional to virtual speed. The screw was coupled to a dual-cone variable-speed drive.

The distance along the range-arm from the pivot to the traveller represented the range. The angle on the bearing-plate corresponded to that between the virtual course and the line-of-bearing.

The clamping-arm was used to set the starting values of range and virtual-course angle.

The note mentioning Pollen's patent was added during the 1925 RCAI hearings.

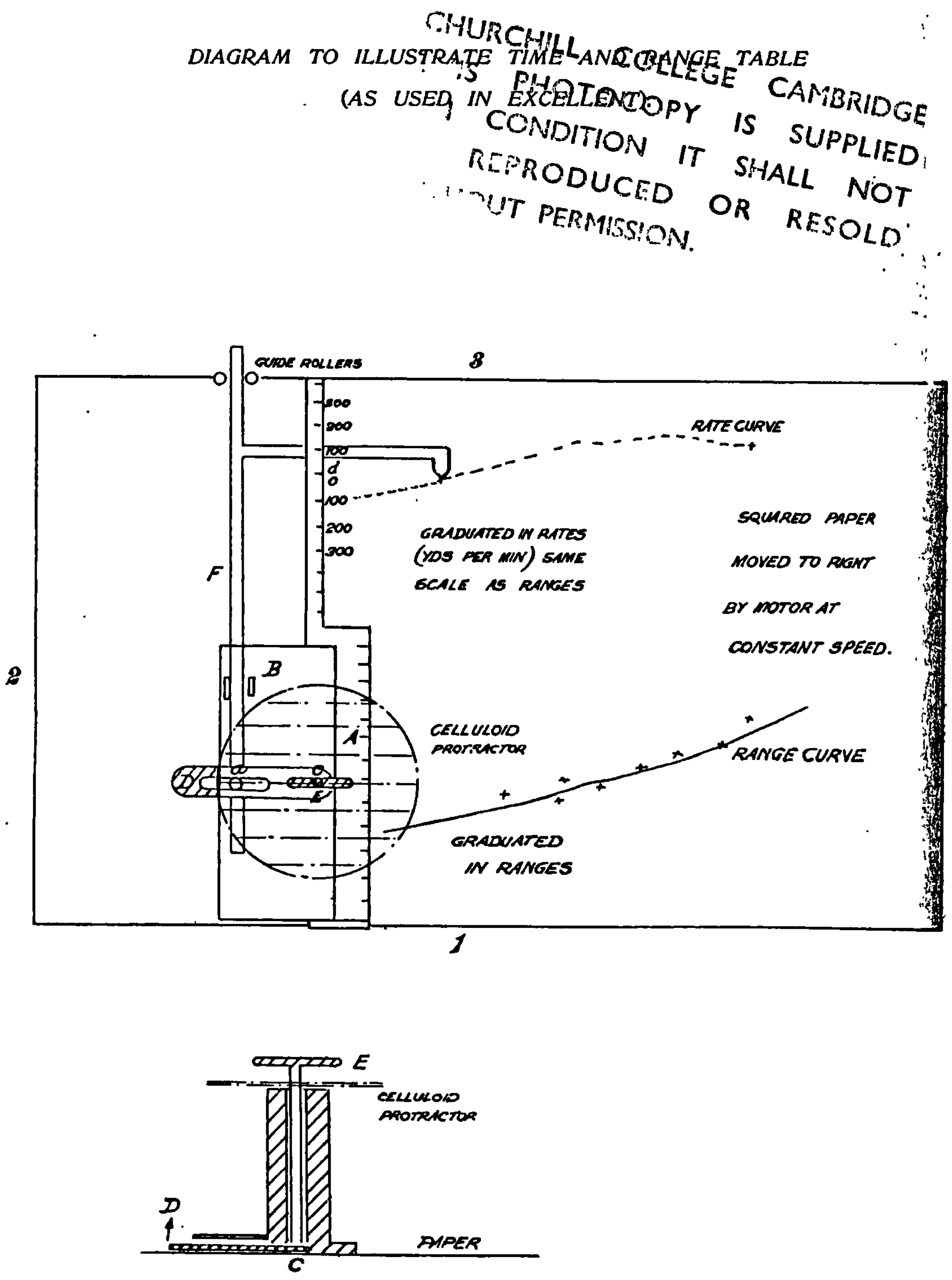
Fig. 1 attached to John to Fred. Dreyer, 17 January 1908 in T.173/91 Part III.



33. John Dreyer's Variable-speed Drive

The lower cone drove the upper through the moveable contact belt. Both cones were coupled to a differential gear. When the belt was in the central position (h'), the cones rotated at equal speed and the differential's output shaft was stationary. By displacing the belt, this shaft was made to turn at different speeds in either direction.

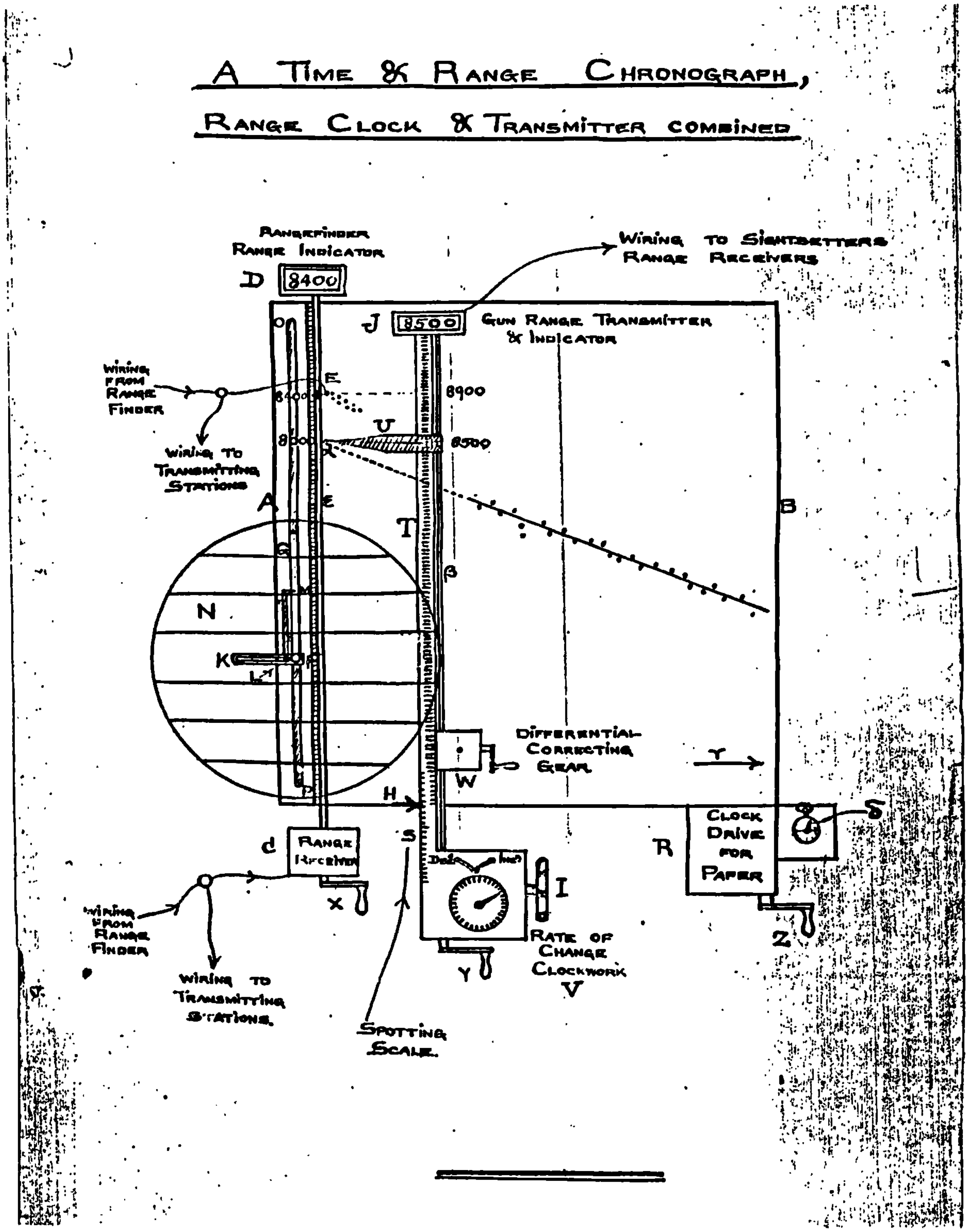
Fig. 2 attached to John to Fred. Dreyer, 17 January 1908 in T.173/91 Part III.



34. Time and Range Table, as used in *Excellent*

The rate was measured off the range plot with the celluloid protractor and plotted automatically.

'Fire Control, An Essay by Captain C. Hughes Onslow, RN', Section III, PLLN 1/5.



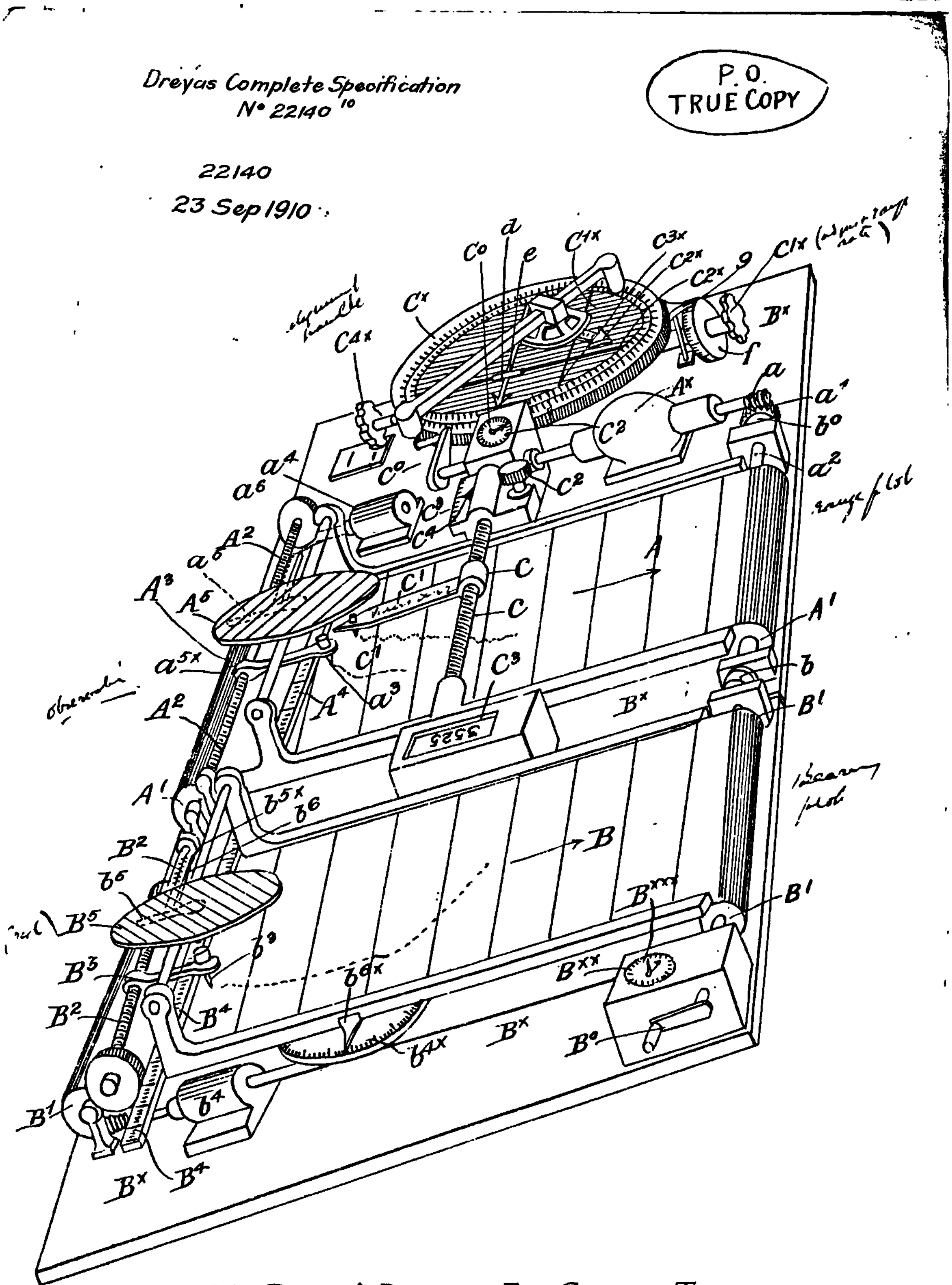
35. Dreyer's Local Control Instrument, 1910

Rangefinder and gun ranges were plotted automatically. When the instrument was set correctly, both plots coincided. Range-rate was measured with the engraved glass disc and set on the rate-of-change clockwork.

The differential gear W corrected the gun-range as transmitted and as indicated by pointer and pencil U.

Rate-of-change clockwork and gun-range scale, pointer and transmitter were all moved bodily with handle I by an amount indicated on spotting-scale S by fixed pointer H.

Dreyer, 'Remarks on Local Turret Control...' in ADM 1/8147 and 1/8131.

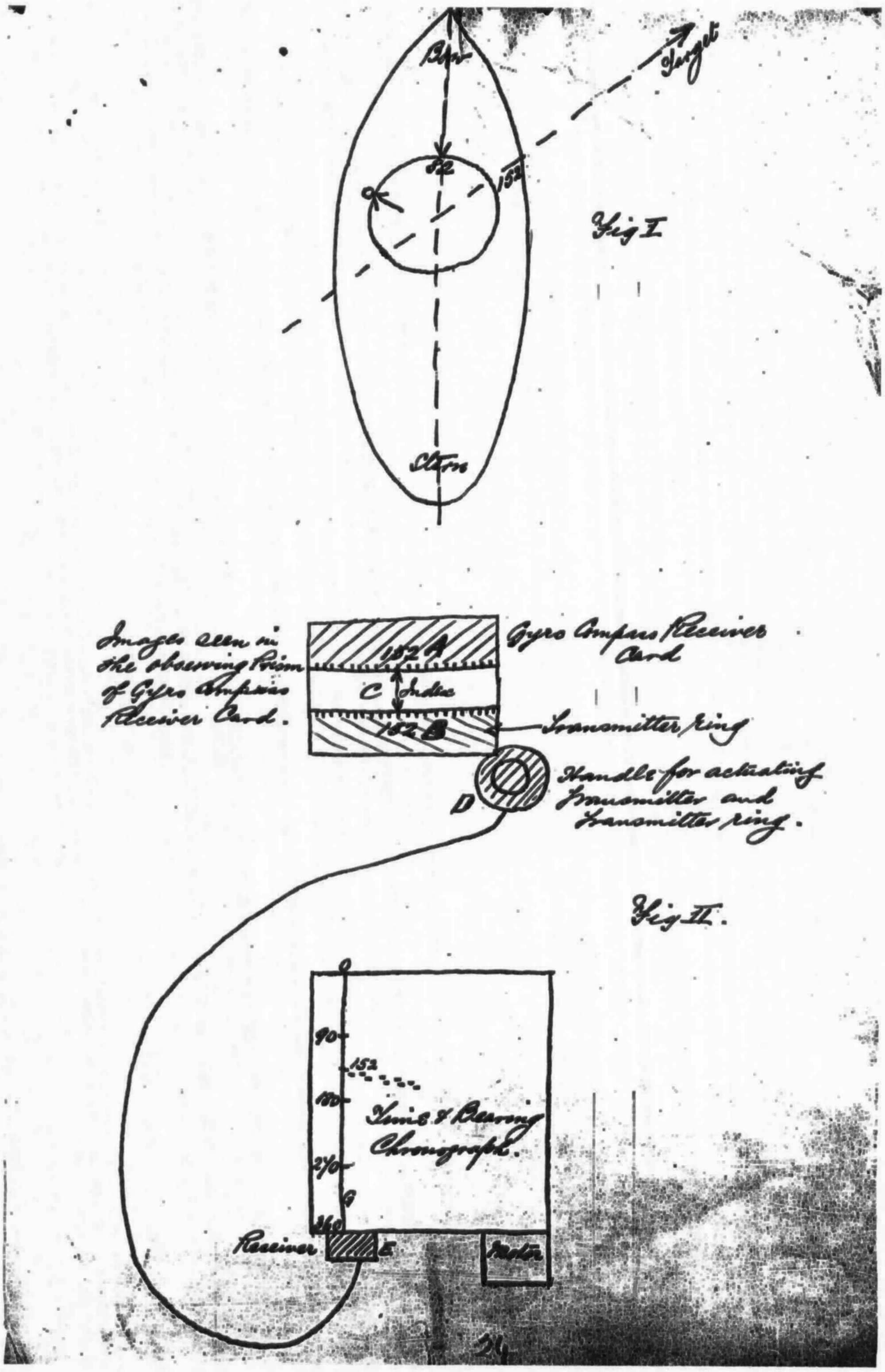


36. Dreyer's Patented Fire Control Table

The clock-rate was set with the wheel on the right side of the Dumaresq by following the bow of the model enemy ship with the pointer d moving in the transverse slot. The handle and small scale (both C^0) were used to set gun-range corrections through a differential.

The range plot was that in the centre of the table. Both the rangefinder and gun-range pointers (to left and right respectively) indicated on a single range-scale A^4. Through a rack-and-pinion mechanism, the knob C^2 displaced the gun-range screw and pointer by an amount indicated on the scale C^2 by the spotting pointer C^4.

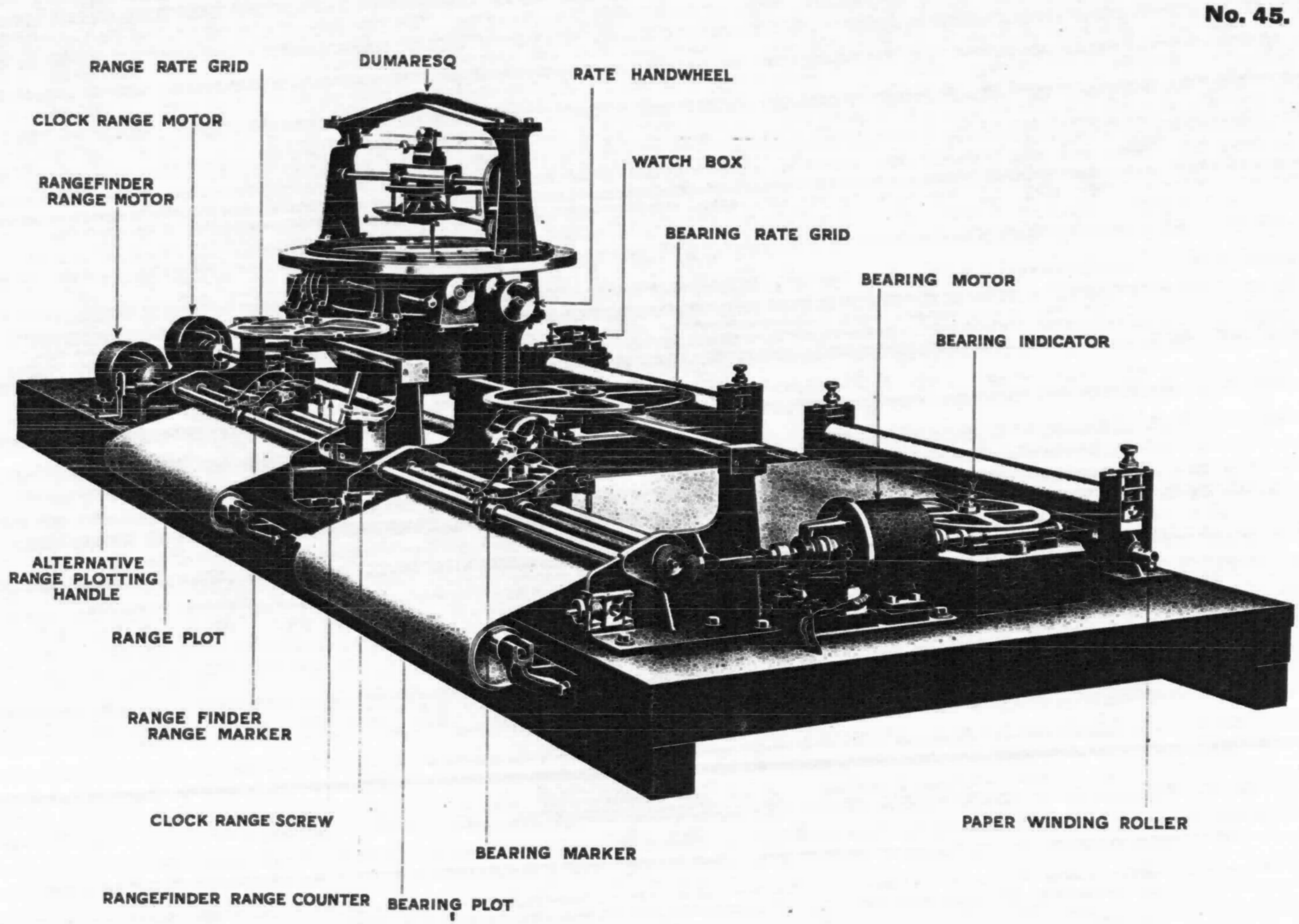
Patent 22,140/1910, Complete Specification 12 April 1912 in T.173/91 Part III.



37. Dreyer's Scheme for Bearing Transmission from a Gyro Compass Receiver

The gyro-compass kept the receiver card fixed in space irrespective of ship's course. The index and transmitter rings rotated outside the receiver card with the rangefinder mounting. To transmit the change of target compass bearing, the transmitter ring was rotated by the transmitter handle until its graduations were again aligned with those on the receiver card.

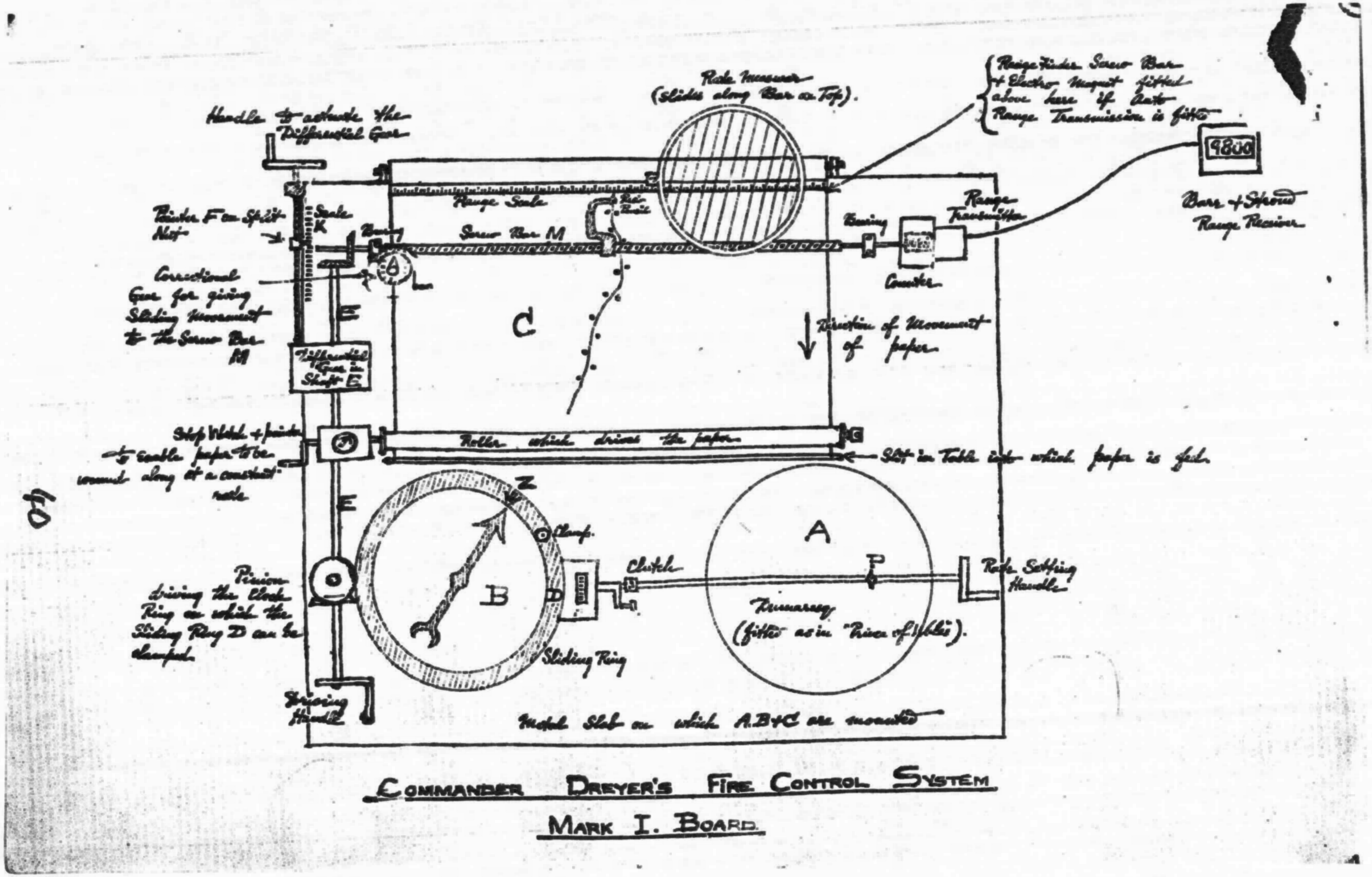
Figures with Dreyer to DNO, 2 December 1910 in T.173/91 Part III.



38. The Original Dreyer Table

The three large receiver motors drove the screws plotting rangefinder and gun ranges and bearings.
The position of the rate handwheel indicated that the slot in the bearing plate of the Dumaresq (a Mark VI) now ran parallel to the plotting screws.
Rates were measured with grids of parallel wires.
The stop-watch in its rotating box was used to check the speed of the electric drive and to regulate the alternative hand drive.

Handbook of Captain F.C. Dreyer's Fire Control Tables 1918, C.B.1456, Plate 45, AL.

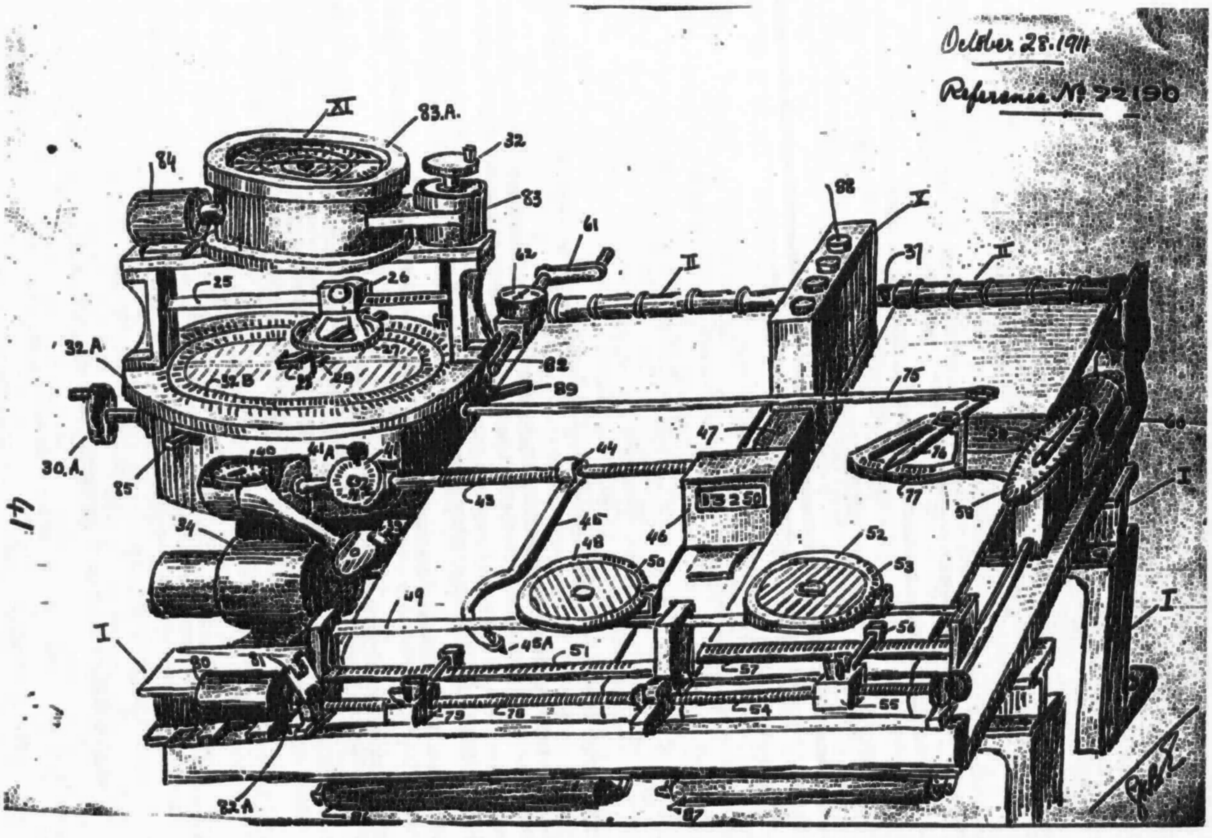


39. DREYER FIRE CONTROL BOARD MARK I

A was a modified Mark VI Dumaresq, B the Vickers clock.

At least five operators were needed: to follow the Dumaresq range-rate, thereby setting the clock-rate: to follow the clock hand with the arrow on the ring: to drive the paper at constant speed regulated by the stop-watch: to apply range corrections with the differential and sliding gears: and to plot rangefinder ranges (this illustration does not show a rangefinder receiver motor) and to read off the plotted range-rate.

'Description of the Apparatus' with Dreyer to Jellicoe, 12 October 1911 in T.173/91 Part III.



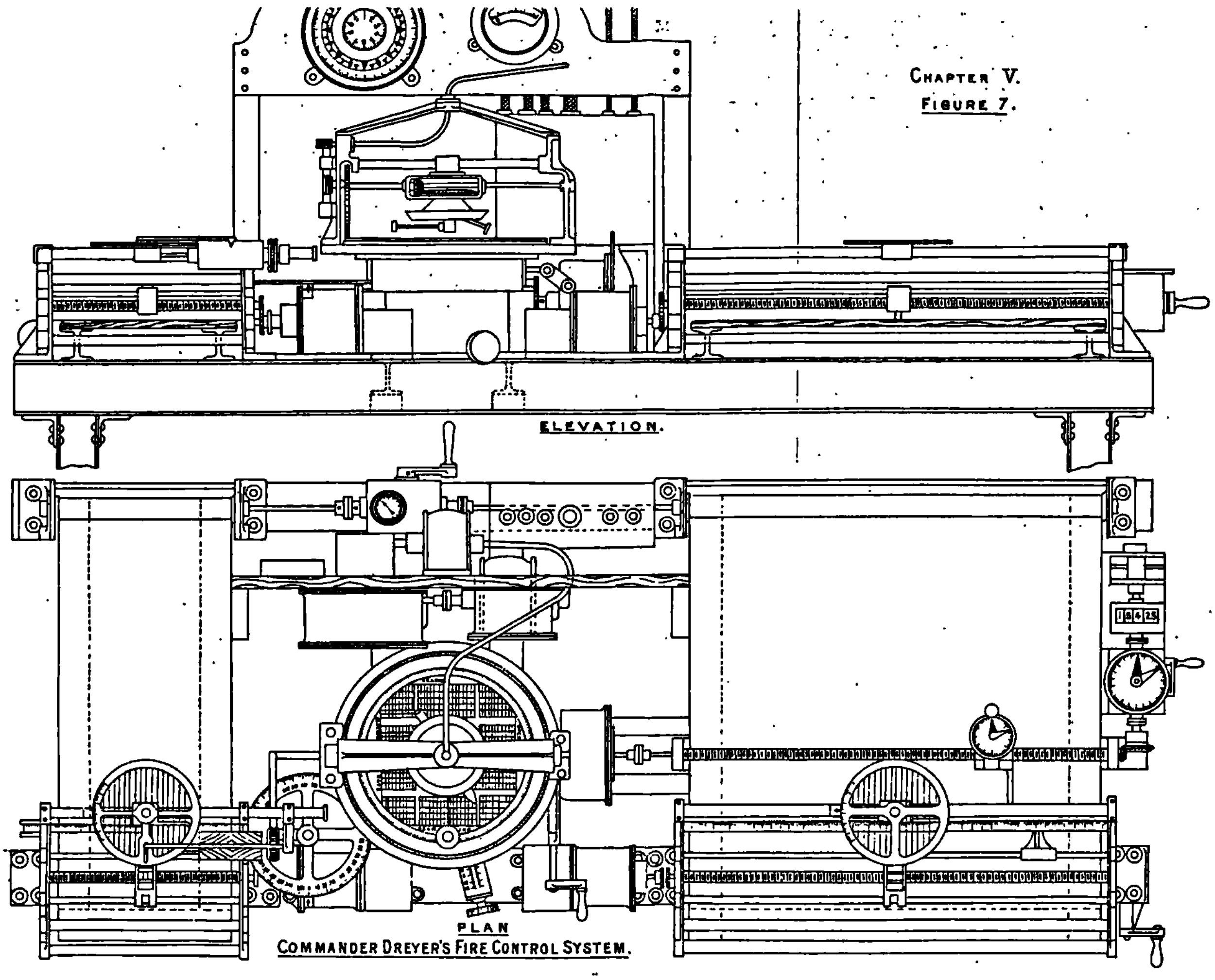
40. Elphinstone's Sketch for the Seven-Part Recorder

The gun-range screw was shifted laterally by a rack, the 'spotting correction' being shown on the small circular scale 41. The large governor-regulated electric motor 3 drove the clocks and advanced the plotting paper.

The gyro-compass receiver was mounted on the bridge above the Dumaresq; the motor 83 applied any change in course to the Dumaresq's compass ring. (Motor 84, which received rangefinder bearings relative to ship's head, was not needed if the rangefinder was on an Argo mounting with a gyro-compass receiver.)

The discs and rollers of the clocks were beneath the Dumaresq. The range clock was now directly coupled to the gun-range screw through a tuning gearbox. The bearing clock was connected (by means unspecified) to the Dumaresq. The pointer 76 and scale 77 indicated the bearing clock's rate; they were located close to the grid 53 so that the rate from the bearing-plot could be transferred easily.

Sketch with Elliott Bros. 'Seven Part Recorder' revised 28 October 1911 in T.173/91 Part III.



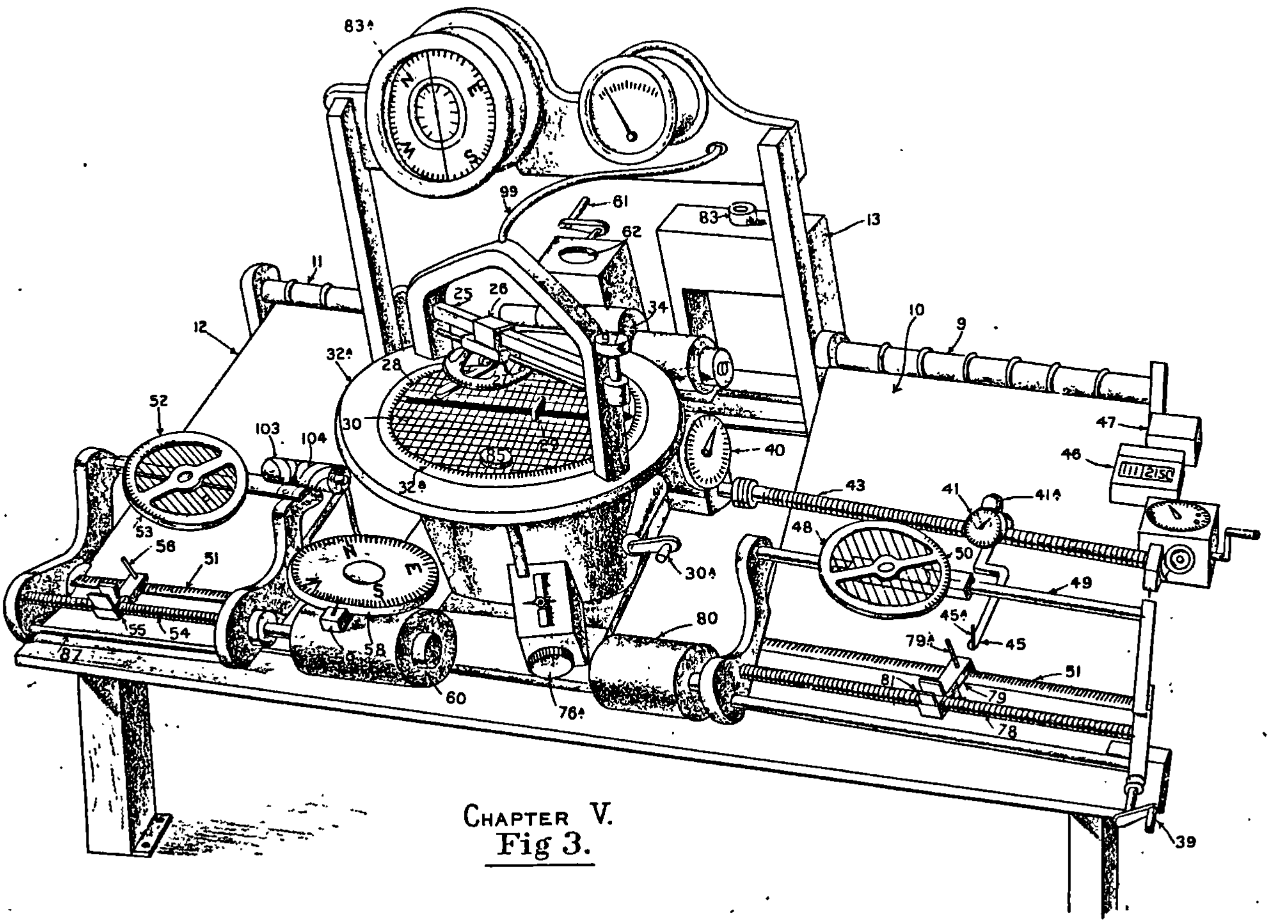
41. Dreyer Table Mark III (1913): Elevation and Plan

The Mark VI Dumaresq, with the clock mechanisms beneath it, is between the plots, the range plot to the right. The Dumaresq dial was graduated in steps of 100 yds/min. for range-rate, 4 knots for speed-across. The scale of the range plot was graduated from 2,000 to 16,400 yards. The rate-scale of the bearing clock was calibrated between ±15°/min.

The receivers for the gyro-compass and Forbes log are on front of the panel above the Dumaresq. The motor-relay on the rear of the panel and its flexible shaft to the Dumaresq can be seen in the plan, which also shows, at the rear of the table, the main drive motor, hand alternative and regulating stop-watch.

The spotting differential is to the right. One hand indicated the total spotting correction while the other was rezeroed after each correction.

Dreyer and Usborne, *Technical History and Technical Comparison...*(1913), Chapter V, p.48 and Fig. 7.



CHAPTER V.
Fig 3.

42. DREYER TABLE MARK III (1913): PERSPECTIVE SKETCH

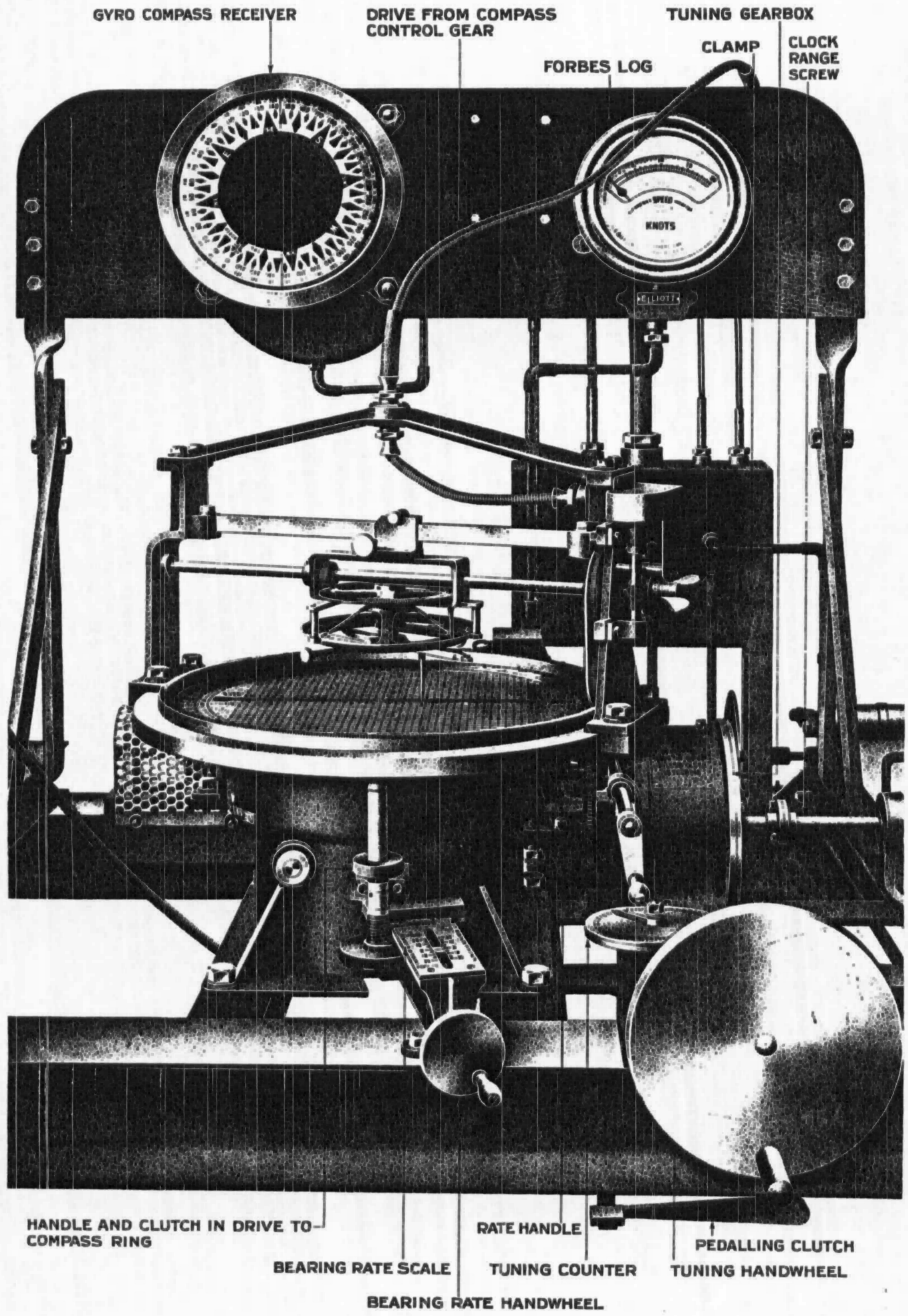
The range and bearing receiver motors and their plotting screws are at the front of each plot. The bearing-receiver also drove the dial 58 indicating target compass bearing.

The rate of the range-clock was set with handle 30^A with the aid of pointer 29. The rate of the bearing-clock was set with the knob 76^A; the bearing-rate was read off the scale of the bearing-grid 52, which could be used either to measure the slope of the bearing-plot, or to convert Dumaresq speed-across into bearing-rate using the curves on drum 103.

The tuning handle 39 was coupled through shafting to the tuning differential 40. The spotting handle and differential are just in front of the gun-range indicator 46 and transmitter 47. The small carriage with dial 41 and wheel 41^A allowed the clock-range pointer 45 to be adjusted without altering the gun-range.

Dreyer and Usborne, *Technical History and Technical Comparison...*(1913), Chapter V, Fig. 3.

No. 23.



Wallage & Gilbert Ltd.

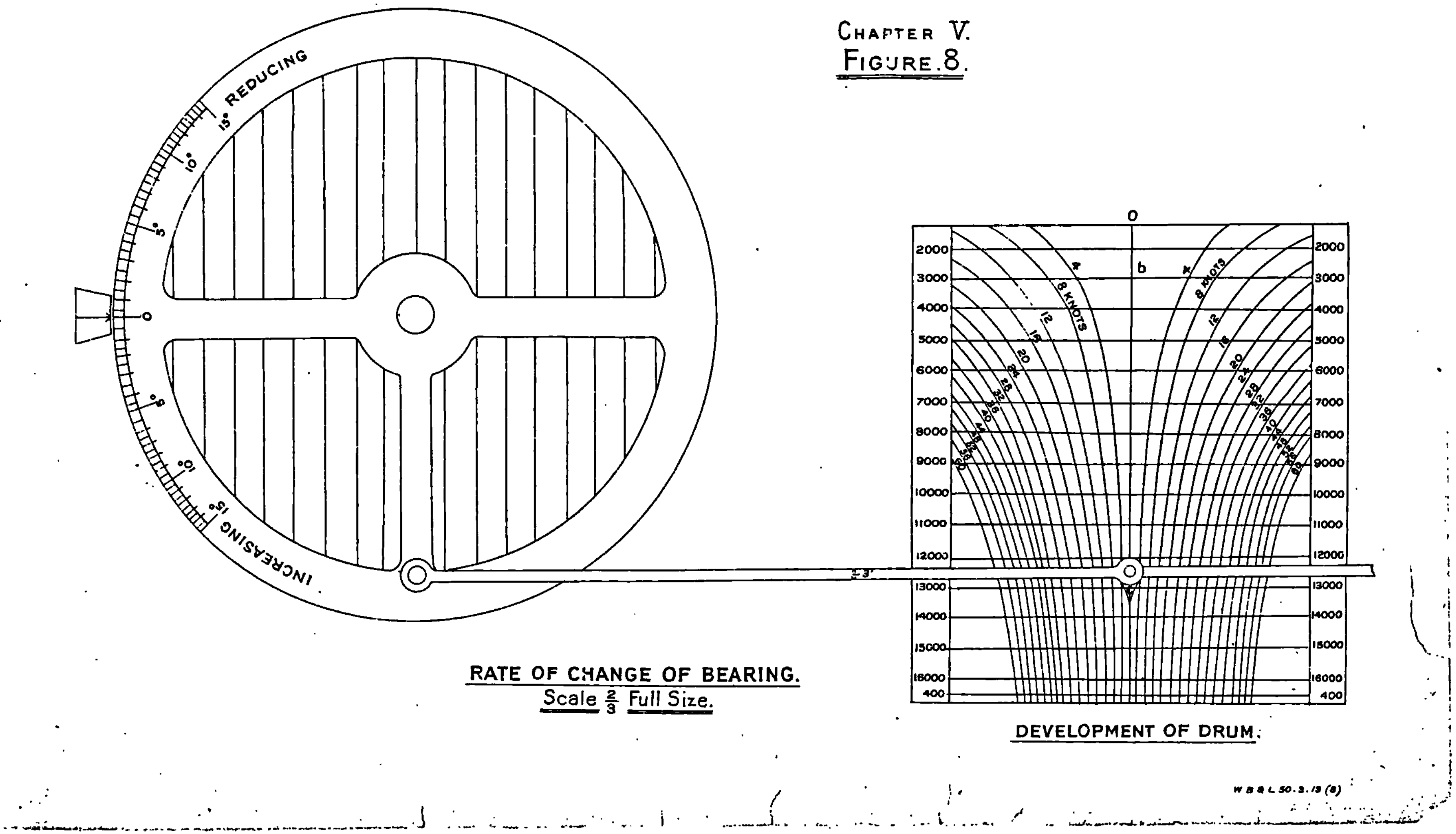
The Dumaresq in the Mark III Table.

43. The Dumaresq Mark VI in the Dreyer Table Mark III

The 'handle and clutch in drive to compass ring' allowed the bearing-clock to be disconnected from the compass ring so that the Dumaresq could be set by hand.

By 1918, the tuning handwheel had been moved to the left side of the range-plot. The 'pedalling clutch' was fitted when the range scale was given two sets of numerals defining ranges up to 16,400 and 24,000 yards, respectively. When engaged, the clutch allowed the tuning handle to alter the clock-range by 8,000 yards without changing the gun-range.

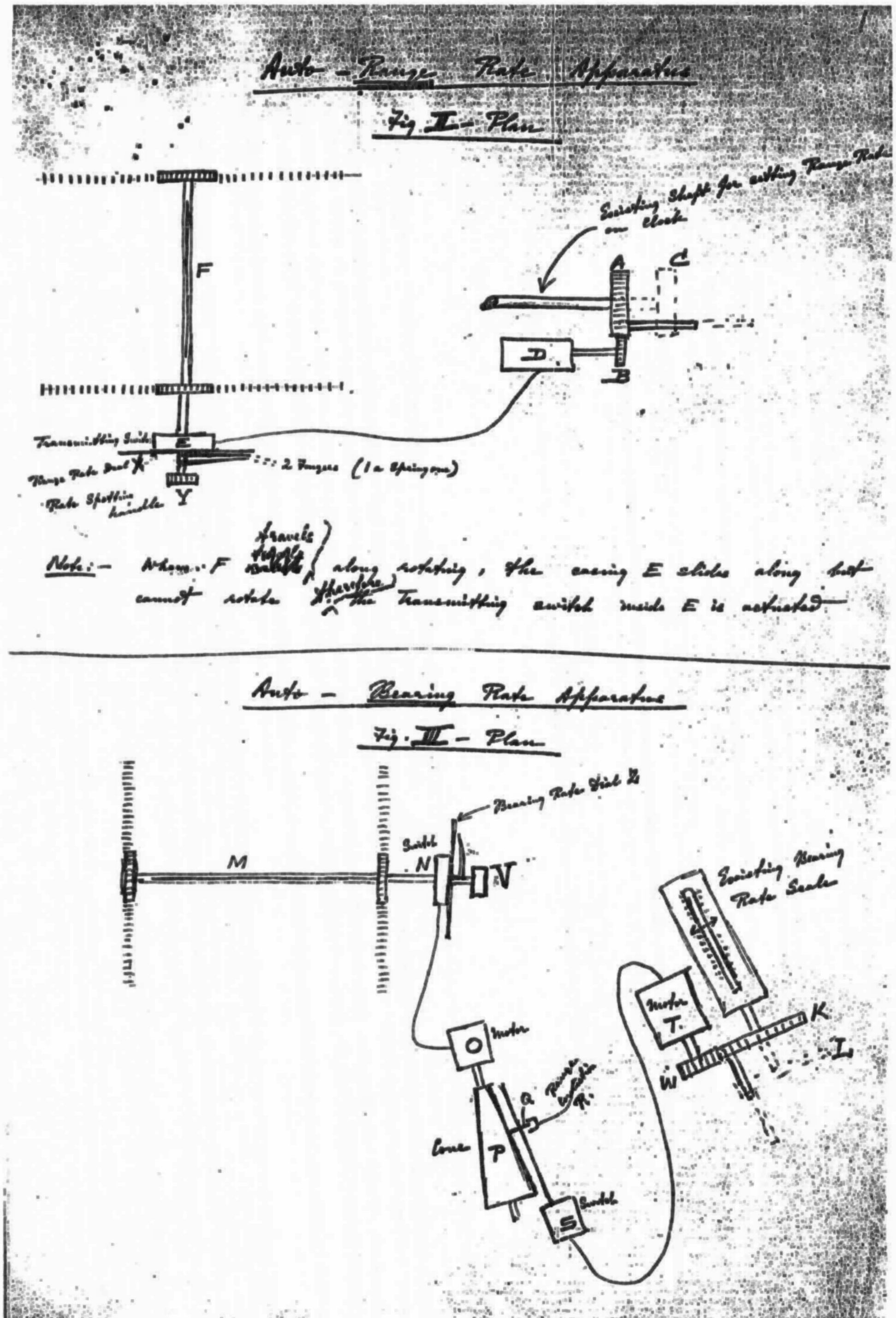
Handbook of Captain F. C. Dreyer's Fire Control Tables 1918, Plate 23.



44. Dreyer Table Mark III: Bearing-Rate Grid and Speed-Across Drum

The grid was used to measure the slope of the bearing plot. Its edge was graduated for bearing-rates between ±15°/min.
The grid was also connected to the sliding pointer indicating on the drum. The drum was coupled to the range-clock so that its position relative to the pointer was set automatically for range. Each curve on the drum corresponded to a speed-across line on the Dumaresq dial. The curves were drawn so that the speed-across indicated by the pointer was always equivalent to the bearing-rate shown on the scale of the bearing grid.

Dreyer and Usborne, *Pollen Aim Corrector System, Part I: Technical History and Technical Comparison with Commander F C Dreyer's Fire Control System*, February 1913, Chapter V, Fig. 8.



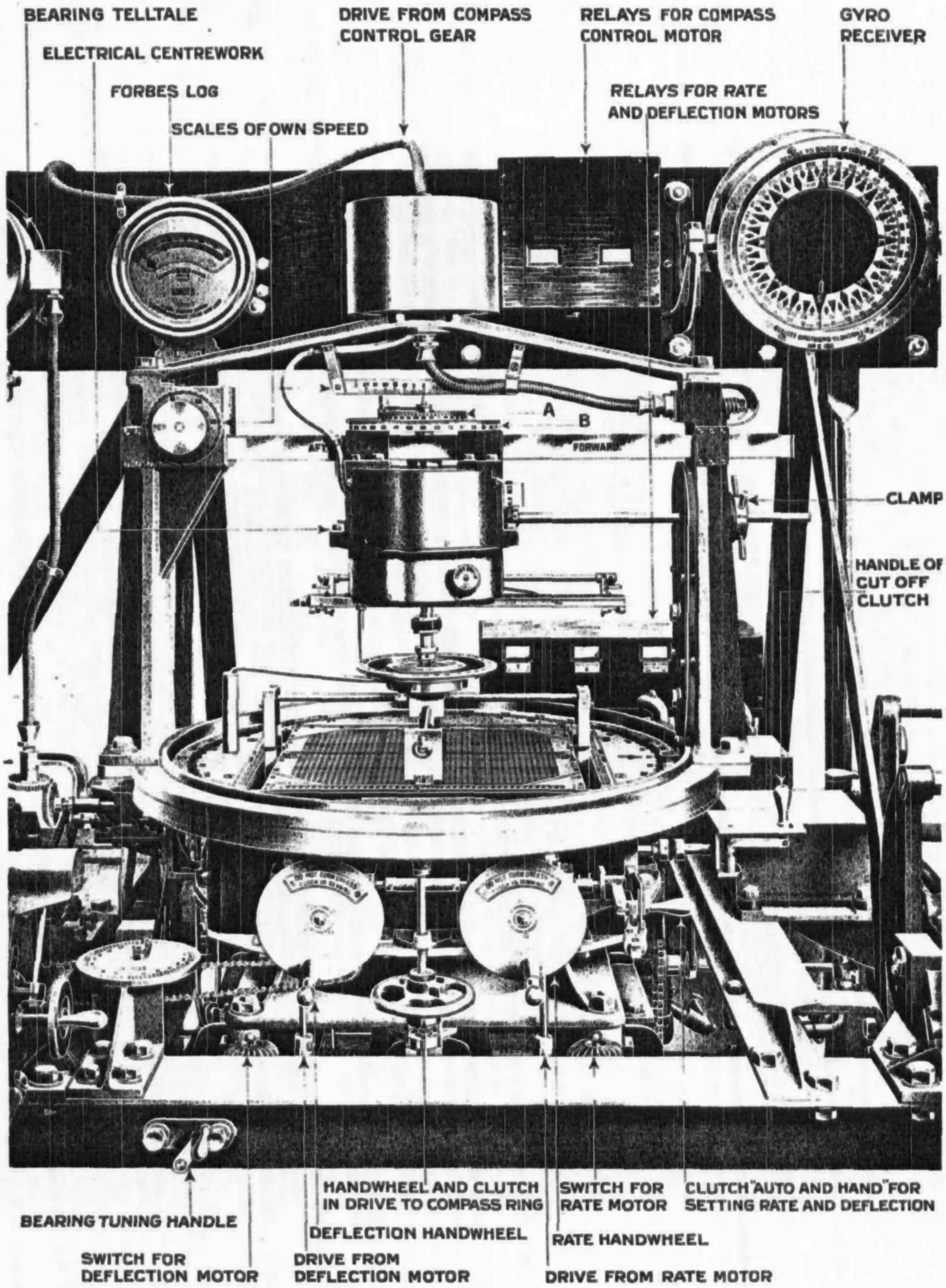
45. Dreyer's Auto-Range Rate Apparatus (December 1913)

A pin extended downward from the bow of the Dumaresq's enemy bar. It engaged with two slotted 'sliders' F and M, which were constrained by the 'fixed spur paths' to move at right angles. As a slider moved, it rotated a transmitting commutator.

The range-rate commutator was wired directly to a step-by-step receiver motor coupled to the roller-slides of the range-clock.

The motor connected to the speed-across commutator drove the cone of a cone-and-roller variable speed drive. The range-clock determined the position of the roller. The roller shaft rotated another commutator, wired to a receiver motor which set the bearing rate.

Figs. II and III with Dreyer to Director of Naval Ordnance, 19 December 1912 in T.173/91 Part III.



The Electrical Dumaresq.

46. Dreyer Tables Mark IV, IV* and V: the Electrical Dumaresq

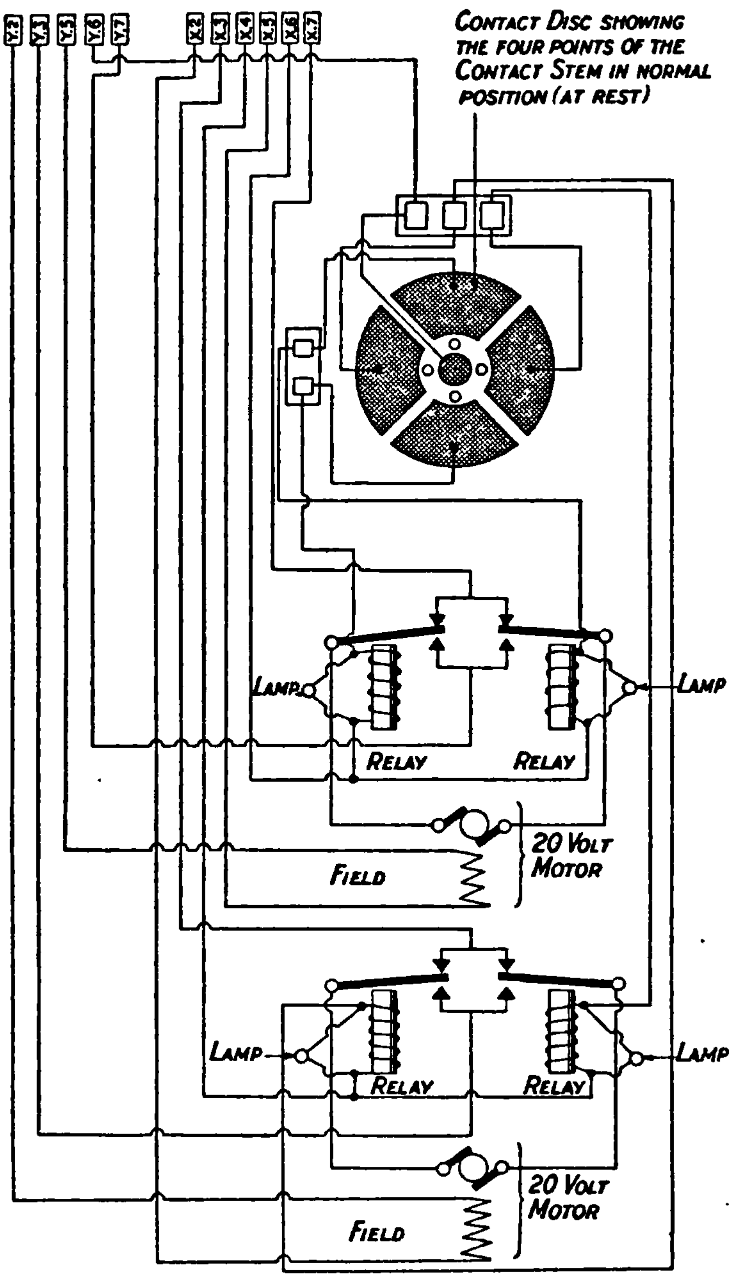
The downwards-extending contact stem replaced the enemy bow pointer. The four contact plungers pressed on the contact plate, which was positioned by the two rods at right angles. The ends of the rods were supported by brackets protruding through slots in the Dumaresq dial. The brackets were positioned by two electric motors, controlled by relays energised through the electric circuits made between the contact-stem plungers and the conducting areas of the contact-plate. Their action kept the contact plate directly beneath the contact stem.

The brackets at front and rear of the dial were coupled directly to the roller carriage of the range-clock. The brackets to left and right were connected to the change-of-bearing gear, which divided Dumaresq speed-across by range to set the rate of the bearing-clock.

(The bearing tuning handle was fitted only to the Mark V Table.)

Handbook of Captain F. C. Dreyer's Fire Control Tables 1918, Plate 24.

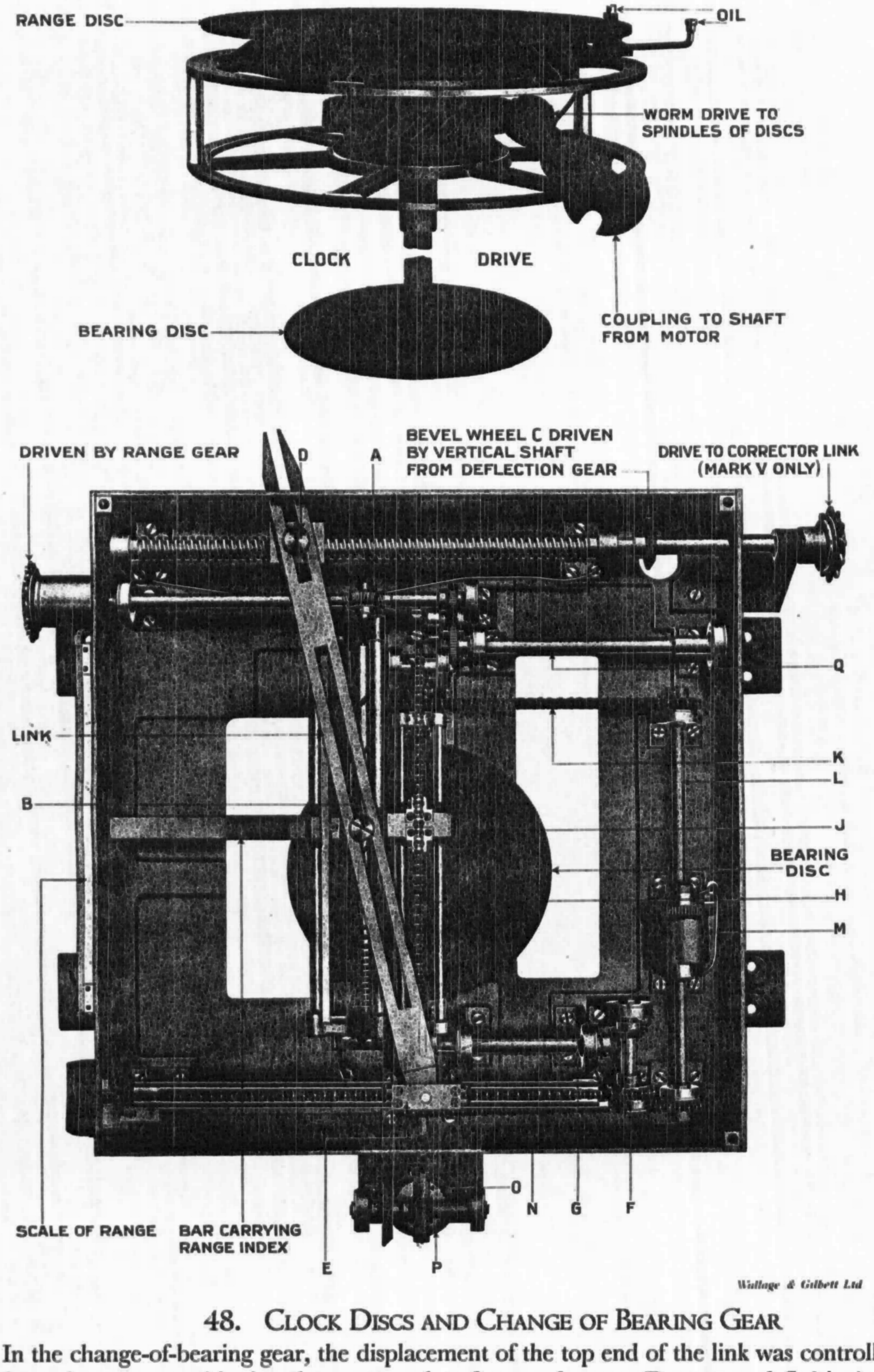
Electrical Dumaresq.]



47. THE ELECTRICAL DUMARESQ: CIRCUIT DIAGRAM

The pattern of conducting areas on the top of the contact plate is shown shaded. When the plate and stem were aligned, the four contacts lay in the circular gap between the conductors. Opposite contacts were connected electrically. If the stem moved out of alignment with the plate, at least one conducting segment was connected to the central circle, thereby energising one of the relays. The relay applied 20 volt power to the appropriate motor with the polarity necessary to drive the contact plate back into alignment with the stem.

Handbook of Captain F. C. Dreyer's Fire Control Tables 1918, p. 54.

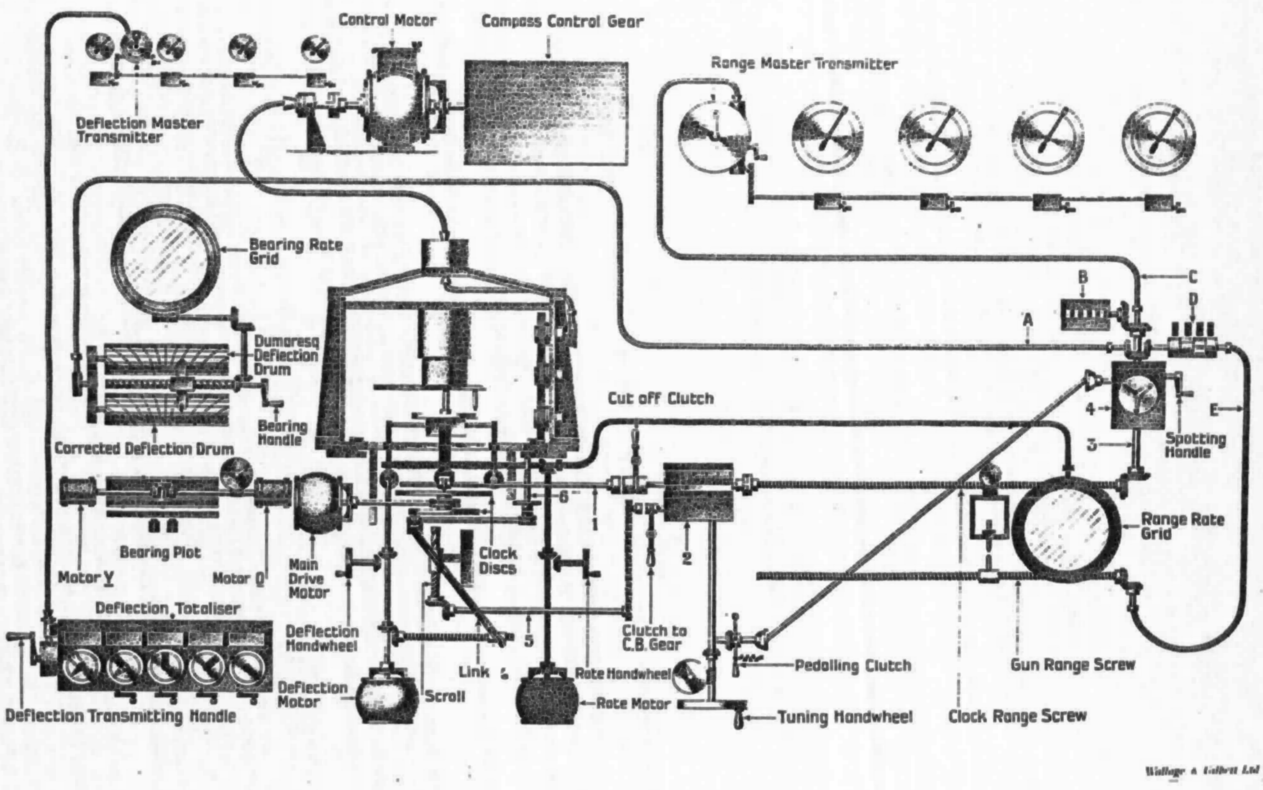


48. Clock Discs and Change of Bearing Gear

In the change-of-bearing gear, the displacement of the top end of the link was controlled directly from the motor positioning the contact plate for speed-across (Dumaresq deflection). The spiral cam was coupled to the range clock and determined to position of the link's central pivot. The cam was cut so that the displacement of the bottom end of the link was proportional to speed-across divided by range. This displacement was conveyed to the bearing-clock roller by the two chains.

Handbook of Captain F. C. Dreyer's Fire Control Tables 1918, Plate 27.

No. 9.



Mark IV and IV* Tables—diagram.

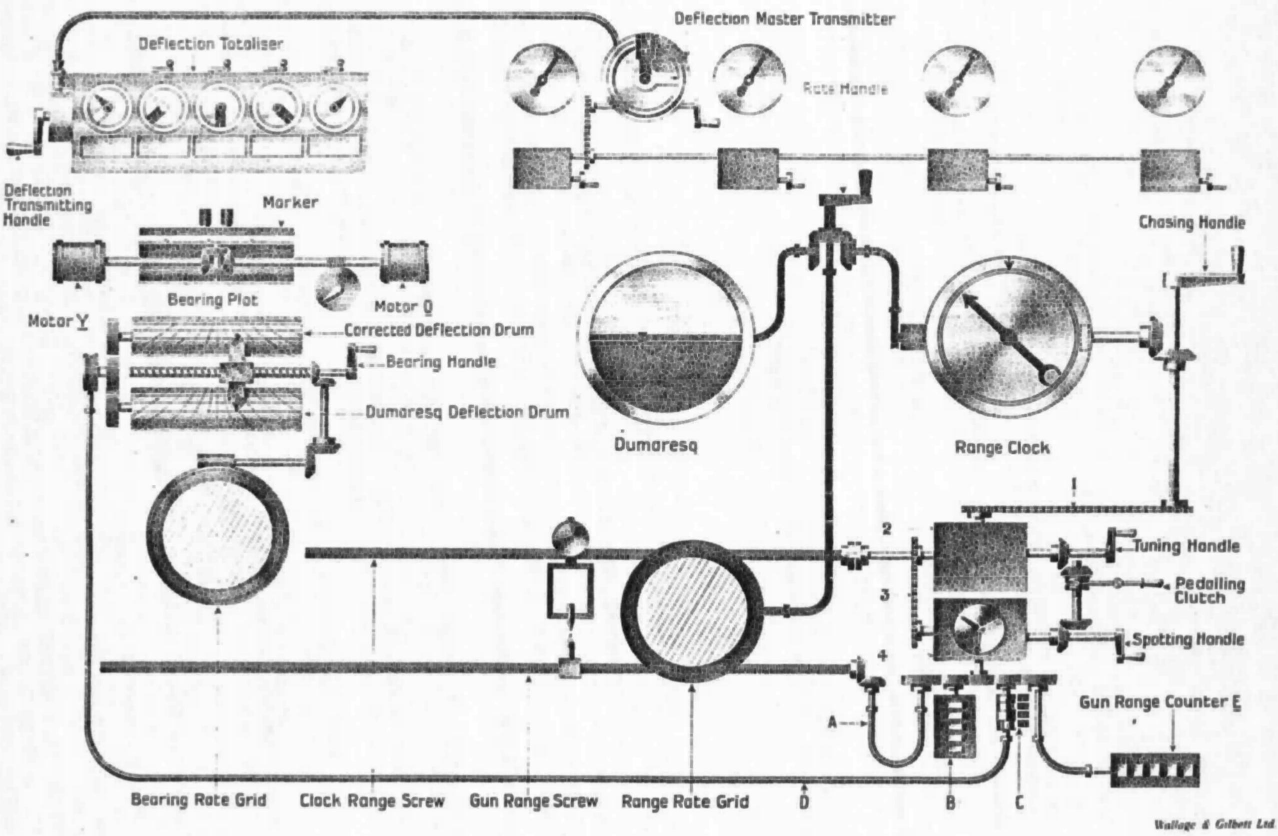
49. Dreyer Tables Mark IV and IV* (1918)

This schematic shows the gun-range screw and deflection totaliser added in 1917, as well as the pedalling clutch. Note the mechanical link from the table to the Range Master Transmitter. The representation of the change-of-bearing gear, though mechanically simplified, shows its operation clearly.

The bearing plot, deflection drums and rate grid were all part of the cancelled standard bearing plotter.

Handbook of Captain F. C. Dreyer's Fire Control Tables 1918, Plate 9.

No. 3.



Mark I Table—diagram.

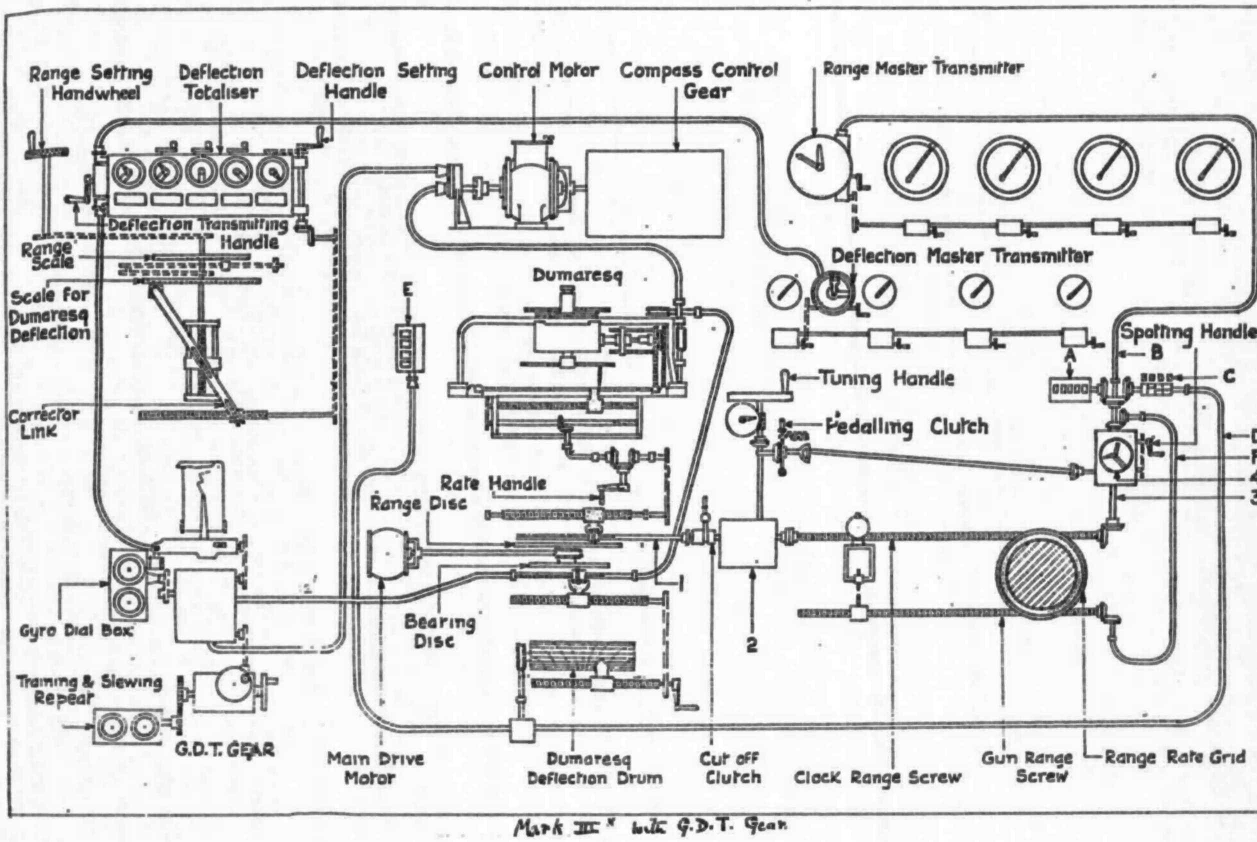
50. Dreyer Table Mark I (1918)

The Rate Handle was coupled through the flexible shafts to the range-clock and the pointer of the Dumaresq. The movements of the clock's range hand was followed with the arrow by means of the chasing handle.

The tuning and spotting gearboxes were together at one end of the plot; the pedalling clutch gear was therefore more compact than in other tables.

Probably only a few tables were fitted with bearing plots, gun-range screws and deflection totalisers.

Handbook of Captain F. C. Dreyer's Fire Control Tables 1918, Plate 3.



Mark III* with G.D.T. Gear

51. Dreyer Table Mark III* with GDT Gear

This cruiser table was based on the Mark VI* Dumaresq and electrically-powered range and bearing clocks. The bearing-rate was set by making the pointer of the Dumaresq Deflection Drum indicate the Dumaresq speed-across. The linkage next to the Deflection Totaliser, when set by hand for range and speed-across, calculated the component of gun deflection due to speed-across.

The GDT gear introduced straight-line plotting, in which the difference was plotted (on a narrow paper strip) between the target bearings as observed from the Director and predicted by the bearing clock. If the target became obscured, the Director fired on the bearing predicted by the clock.

Handbook of Captain F. C. Dreyer's Fire Control Tables 1918, insert.

6

War and its Lessons

The engagements fought by British battlecruisers in 1914 and early 1915 soon demonstrated the realities of gunnery in action. On 28 August 1914, the conditions in the Heligoland Bight[1] confirmed per-War apprehensions about visibility in the North Sea.

> The enemy first appeared...at about 7,500 [yards] ships being on closing courses. ...when the "Commence" was sounded, no range had been taken, nor was it possible to take any afterwards.
>
> ....
>
> The range on the sights on opening fire was 6,000 but this was rapidly spotted down to 5,200 and first straddle was obtained at a range of about 5,000....

Lion's Captain Chatfield considered that 'the gunlayers were probably unduly hurried' and that 'under short visibility conditions ...slow and deliberate firing with turret guns will be as effective as rapid and great waste of ammunition will be avoided'.[2] His report resulted in the Admiralty issuing orders 'to avoid waste of ammunition';[3] this emphasis was to have unfortunate consequences during *Lion's* next major engagement.[4]

At the Battle of the Falkland Islands (8 December 1914), Admiral Sturdee used the superior speed of *Invincible* and *Inflexible* to force an engagement at ranges long enough to overwhelm Spee's two armoured cruisers with little damage to the British ships.[5] Throughout, the British battlecruisers remained to windward and were severely

[1] Arthur Marder, *From the Dreadnought to Scapa Flow, Vol. II* (London, 1965) pp.50-54. Stephen Roskill, *Admiral of the Fleet Earl Beatty* (New York, 1981) pp.82-85. Beatty's despatch, 30 August 1914 in Brian McL Ranft (ed.) *The Beatty Papers, Volume I* (Aldershot, 1989) pp.122-6.

[2] 'Remarks on Cruiser Action of 28th August' with Captain Chatfield to VAC First Battle-Cruiser Squadron, 31 August 1914 in ADM 1/8391/286, PRO. See also *Beatty Papers I* (*op. cit.*) pp.127-9.

[3] DNO's minute, 8 September 1914 in ADM 1/8391/286.

[4] For Admiralty concerns about shortages, particularly of cordite, see Iain McCallum, 'Achilles Heel? Propellants and High Explosives, 1880-1916' in *War Studies Journal*, Vol. 4, Iss. 1, Summer 1999, pp.76-8 (author's copy gratefully acknowledged).

[5] *FDSF II* (*op. cit.*) pp.121-3: Paul Halpern, *A Naval History of World War I* (London, 1994) pp.98-9.

handicapped by their own smoke;[6] at one point, they were forced to turn about to cross the German wake and, then and later, were on opposite courses to their targets.[7] *Invincible's* gunnery report emphasised that, from the foretop (her principal fire control position):

> Range taking was impossible during the greater part of the action, due to funnel smoke, gun smoke, etc.
> Rangefinder was on several occasions covered with spray from shell bursting short.

Similarly, ranging from turrets was most difficult, often impossible: while, without directors,[8] aiming with the turret gunsights was also badly affected. Furthermore:

> Great difficulty [was found] in keeping the shot on the target due to the rate constantly changing. This appears to have been due to the enemy zigzagging, and at the long range these alterations of course, in and out, could not be detected by eye or by rangefinder.
> ....
> It was often very difficult to see overs, or hits, unless a bright flame accompanied the hits.[9]

For most of the action, *Invincible's* foremast suffered from considerable shaking following an 8.2-inch hit on the starboard strut: yet the effect on rangetaking from the top with the Argo rangefinder was not even mentioned explicitly in her reports.[10] Nor, indeed, is the making of range plots. It appears that rangefinding was so difficult, due to smoke and the long ranges, that few usable ranges were obtained; thus, particularly with the enemy zig-zagging, most reliance had to be placed on spotting.

The Battle of the Dogger Bank, on 24 January 1915, was a protracted stern chase to the SE, Hipper (leading in *Seydlitz* and followed by *Moltke*, *Derfflinger* and *Blücher*) being pursued by Beatty's five battlecruisers, in order *Lion*, *Tiger*, *Princess Royal*, *New Zealand* and *Indomitable*.[11] With a light wind from the NE, Beatty chose the orthodox lee position, in which the smoke from his own ships would not interfere with gunnery. At 8.52, *Lion*

[6] 50. 'Report of action off the Falkland Islands', *Grand Fleet Gunnery and Torpedo Orders* (to 15 September 1915) p.15, ADM 137/293.

[7] Vice-Admiral Sturdee, 'Report of the Action off the Falkland Islands', 8 December 1914 and *Inflexible*, 'Report on Action...off Falkland Islands...' (with Enclosure) 11 December 1914 in ADM 137/304.

[8] John Brooks, 'Percy Scott and the Director' in David McLean and Antony Preston (eds.) *Warship 1996* (London, 1996) p.168.

[9] 'Gunnery Remarks' and 'Damage caused to H.M.S. "Invincible" by Gunfire...', with *Invincible* to C.-in-C. S. Atlantic & S. Pacific, 18 December 1914 in ADM 137/304.

[10] Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) pp.297-8 does not refer to the hit on the mast, stating only that 'the Argo mounting had been placed at the top of the fore-mast, where vibration from the high speed...and funnel smoke rendered it useless'.

[11] For general accounts of the battle, see *FDSF II*, pp.156-174: Roskill, *Beatty* (*op. cit.*) pp.108-120: James Goldrick, *The King's Ships Were at Sea* (Annapolis, 1984) pp.248-302. Reports are in ADM 137/305, the majority reproduced in *Beatty Papers I*, pp.206-248.

opened on *Blücher* with a single shot at the unprecedented range of 20,000 yards; *Tiger* and *Princess Royal* also selected the same target shortly thereafter: but *New Zealand* and *Indomitable* were already falling behind. Though *Princess Royal* also could not keep up, *Lion* pressed ahead, accompanied by *Tiger*. However, *Tiger's* fire was largely ineffective, which Beatty attributed to her failure to obtain 'that proportion of short shots which is usually considered essential for effective control';[12] it also appears that other British battlecruisers made the same mistake.

> ...it is absolutely misleading to think hits will be seen, at any rate at long range. Shorts are the only guide, and the great value of them must be impressed on control officers.[13]

Furthermore, *Tiger* also ignored Beatty's order to fire at opposite numbers, leaving *Moltke* free to concentrate with *Seydlitz* on the British flagship. The critical moment came at about 9.50, when a hit from *Lion* started a cordite fire which gutted both after turrets in *Seydlitz*. Unfortunately, as Chatfield admitted:

> The mistake made was in not at once going into Rapid Independent and putting forth our whole volume of fire regardless of ammunition expenditure. Enemy would then have been overwhelmed and never recovered.

Thus *Seydlitz* was able to continue firing with her fore and starboard-wing turret and *Lion's* shooting was soon severely disrupted.

> The enemy's fire was slow at first but got faster, and at the end was a maximum. *Lion's* fire was fairly quick at first, but got slower, due to the enemy's shorts interfering with gunlaying, spotting and control, until eventually it was almost impossible to return the fire...[14]

After 10 o'clock, *Lion* continued to bear the brunt of the German fire. From 10.35, she was struck repeatedly until, at about 10.50, the port engine had to be stopped and she was forced to quit the line. She was overhauled by *Tiger* but Beatty's final flag signals turned his other ships NE'wards to concentrate on the *Blücher*,[15] while Hipper's battlecruisers escaped, though not before inflicting significant damage on *Tiger*.

Beatty's ships did not obtain the advantage expected from their lee position. The wind blew spray from the bows and from enemy shorts onto the instrument glasses, while

[12] Beatty to Pelly, 11 February 1915 in *Beatty Papers I*, pp.246-7. *Tiger* also did not use her 'time-of-flight arrangements'.

[13] Chatfield to Beatty, 'Remarks on the Action, 24th January 1915', 2 February 1915 in *Beatty Papers I*, p.232.

[14] *ibid.* p.231; despite his own report, Chatfield also regretted 'the general impression there has been since 28th August that ammunition expenditure must not be excessive'. See also Lord Chatfield, *The Navy and Defence* (London, 1942) pp.126-7.

[15] Andrew Gordon, *The Rules of the Game* (London, 1996) pp.94-5. Goldrick, *King's Ships* (*op. cit.*) pp.272-5. Moore to Beatty, 7 February 1915 in *Beatty Papers I*, pp.219-220.

the smoke from the German ships was carried almost directly down-range, causing both sides severe interference to ranging, aiming and spotting.[16] Much of the firing was at ranges close to the limits marked on the sights; the *minimum* range recorded in *Lion's* TS was a momentary 14,825 yards at 10.29½. The Argo transmission gear was designed for a maximum range of 16,000 yards, so the only means of conveying most ranges from the Argo Tower was by voice-pipe.[17] *Tiger* also reported that 'very few ranges were obtained and no attempt was made either to obtain or keep a rate'.[18]

> Little use could be made of the rangefinders as few cuts could be obtained, whilst the range was too great for accurate readings to be taken; time and range plotting was impracticable.[19]

In contrast, a bearing plot was maintained in *Lion* until about 10 o'clock. This probably helped her to open with, and then keep, a correct deflection. However, the officer commanding the Fore TS concluded:

> On the whole I do not consider that the Dreyer table has justified its existence and that until rangefinders have been made more accurate and the difficulties of spray, etc. in turrets, overcome [more] energy should be devoted to the bearing plot, which if the yaw can be eliminated, should give accurate results.[20]

Since the yaw was taken out in the Argo mounting before transmission to the Mark III table, this comment clearly implies that the gyro stabilisation was only partially effective.

By zig-zagging, *Lion* threw out her opponents' fire for a short time and both Beatty and Chatfield recommended alterations of 2 points (1 point at high speed) with small helm to this end. The former added:

> This has often been practised and will in no way interfere with our gunnery.

which indicates confidence in the helm-free operation of the Dreyer Tables Mark III and IV (and, indeed, the compensation for course-change incorporated in the Mark VI Dumaresq). However, against a zig-zagging target:

> Rates and Dumaresqs become almost useless....Rangefinders may help but spotting must be the primary aid for keeping on the target.[21]

After the Dogger Bank action, Chatfield concluded:

[16] Hipper's despatch in Hugo von Waldeyer-Hortz, *Admiral von Hipper* (London, 1933) p.152. Chatfield to VAC, 1BCS, 27 January 1915 and Pelly, 'Gunnery Notes' in *Beatty Papers I*, pp.211 and 241.
[17] *Lion's* gunnery reports with the copy of Chatfield, 'Remarks' in ADM 137/305.
[18] Pelly, 'Gunnery Notes' (*op. cit.*) p.241.
[19] '51. Remarks on Action on 24 January 1915' in *GFG&TO* (*op. cit.*) p.17.
[20] *Lion's* gunnery reports (*op. cit.*).
[21] Chatfield to VAC, 27 January 1915 in *Beatty Papers* I, p.212. Chatfield, 'Remarks' (*op. cit.*) p.232. Beatty, 'Notes re Lessons Learned...' in *Beatty Papers I*, p.224.

> It is certain that Battle Cruisers, and probably Battleships, may have to open fire at much greater ranges than 15,000 yards, and that rapid fire will be employed by the enemy at 18,000, which must be answered by rapid fire.[22]

Beatty's emphasis, while showing a surprisingly complacent view of his ships' gunnery, was quite different.

> The Falkland Is. fight, and 24th January, have proved that hits can be made without difficulty [*sic*] at 19 or 20000 yards, but this range is not decisive and the percentage of hits is too small.
> ...we must try and get in closer without delay. Probably 12,000 to 14,000 yards would suit us well, this being outside the effective range of enemy's torpedoes and 6" guns.[23]

These divergent views would have an important bearing on their next encounter with Hipper's battlecruisers.

GERMAN FIRE CONTROL[24]

What is known of the German fire control system, which had shown itself to be all too effective, even from a disadvantageous position? Their fire was normally directed from the fore control position, an armoured tower in the rear of the conning tower. This and the reserve position aft were linked by telephone and voice pipe to the transmitting stations beneath the armoured deck; gunnery data and orders were thence transmitted electrically to the turrets by fire control instruments from Siemens and Halske.[25] All the battlecruisers were fitted with Zeiss 3-metre stereoscopic rangefinders; these were installed under turret roofs and above the control towers, particular reliance being placed on the latter type.[26] As explained in Appendix XXV, straightforward comparisons are difficult, but it appears that, especially at ranges above 15,000 yards or so, the Zeiss 3-metre was more accurate than the Barr and Stroud 9-foot FQ2, but no better than the 15-foot FX24. In addition, stereoscopic rangefinders were sometimes able to obtain ranges when

[22] Chatfield, 'Remarks'.
[23] Beatty 'Lessons' (*op. cit.*).
[24] See Appendix XXIV for development history and technical details.
[25] Georg von Hase *Kiel and Jutland* (London, 1921) pp.77-9. Naval Staff, Intelligence Department, *Report on Interned German Vessels. Gunnery Information*, February 1919, pp.8 and 18, ADM 186/240. Guy Hartcup, *The War of Invention* (London, 1989) pp.12 and 14.
[26] *Interned German Vessels*, 1919 (*op. cit.*) pp.8,17 and 34-5. Naval Staff, Intelligence Division, *Reports on Interned German Vessels, Part V Gunnery Material*, October 1920 (C.B. 1516E), pp.7-9, ADM186/243. *Seydlitz*, 'General Experience' in 'Jutland, Later Reports', f.272, ADM 137/1644. Naval Staff, Intelligence Department, *German Gunnery Information Derived from the Interrogation of Prisoners of War*, October 1918 (C.B.01481), pp.18 and 22, Ca 0108, AL. von Hase (*op. cit.*) pp.79 and 148.

coincidence instruments could not, notably when a target was almost shrouded in smoke.[27]

Ranges were transmitted electrically from the rangefinders to the control positions by the 'Basis Gerät':[28] but mean range and rate were never obtained by any form of plotting. From 1908, range-rate only was obtained from the EU-Anzeiger, while a similar but separate instrument indicated deflection; both worked on the same principles as the British Dumaresq, though neither had any special features to assist in keeping the rates (albeit approximately) during a turn by own ship.[29] From 1912, range-rate was set on a range clock; the more recent model described in wartime intelligence reports (Plate 52) was probably the Aw-Geber C.12 Elevation Telegraph, which automatically converted clock-range into elevation, the latter then being transmitted directly to follow-the-pointer gun-sights.[30] By the time of Jutland, the German Navy had introduced a training director, which transmitted corrected bearing angles to all the turrets from the control position.[31] However, gun laying remained the responsibility of the individual layers, who were accustomed to aim continuously and preferred to fire their own pieces once the fire gong had sounded;[32] thus, at Jutland, several British observers described the German salvoes as rapid ripples.[33]

> In spite of the rapid motion of the ship the gun-layer must make it his business to see that the sight of the gun is *always* kept trained on the enemy...shooting on a rolling ship was one of the most important feature of our crews' training on the high seas.[34]

Accurate aiming ensured that salvoes were closely grouped: and that, when straddling, about 25% of shots could be kept falling short. It also permitted a rather different (and

[27] For comparative trials held after the War, see Admiralty, Gunnery Branch, *Progress in Gunnery Material 1922 and 1923*, November 1923, pp.38, 42-9, 51 and 56-7, ADM 186/259.
[28] Literally 'base- or pedestal-gear' but frequently used to include the transmitter as well; von Hase, p.79: Admiralty, *German Navy, Part IV Section 4, Target Practice, Rangefinders and Control of Fire*, July 1917 (C.B. 1182A) p.16, Ca 0106, AL: *Seydlitz*, 'Experience' (*op. cit.*).
[29] Peter Padfield, *Guns at Sea* (London, 1974) p.228. *Information from PoWs*, 1918 (*op. cit.*) pp.16-17.
[30] *Information from PoWs*, 1918, p.16. Karl Lautenschläger, 'The Dreadnought Revolution Reconsidered' in Daniel Masterson (ed.) *Naval History, The Sixth Symposium of the U.S. Naval Academy* (Wilmington, Delaware: 1987) p.135. von Hase, pp.82-3.
[31] Padfield, *Guns at Sea* (*op. cit.*) p.252. Lautenschläger, 'Dreadnought Revolution', (*op. cit.*) p.135. John Campbell, *Warship Special 1. Battlecruisers* (London, 1978) pp.19, 22, 43 and 49. *Seydlitz*, ' Experience', f.271. von Hase, pp.80-1.
[32] *Information from PoWs*, p.19.
[33] Jellicoe to the Secretary of the Admiralty, 18 June 1916 (Secret Report) f.40 in ADM 137/301. Midshipman P M S Blackett, 'Naval Diary 1914 - 1918' (transcribed by Dr Nicholas Blackett) 31 May 1916.
[34] von Hase, pp.82-3.

sometimes more rapid) method of bracketing from that used by the Royal Navy. Attempts to estimate the distance over were forbidden but:

> It is desirable that we should train our assistant observers to such an extent that when short shots occur they will be able to tell the fire commander with certainty what size of bracket will suffice.[35]

Between the Dogger Bank and Jutland, the Germans introduced an instrument which calculated the mean of the ranges received from up to eight rangefinders. The officer in charge could also switch out any rangefinder ranges which appeared to be anomalous; he also reported 'the change of range per minute calculated from the difference of the range-finder readings'. This instrument, called the 'Mittlungs Apparat' in intelligence reports, provided a mean range to set on the range-clock:[36] and an alternative value for range-rate to that obtained from the EU-Anzeiger. At Jutland, *Derfflinger* had also been supplied with a new instrument which kept both range-rate and deflection. This was very probably the device called the Z31 EU/SV-Anzeiger (Plate 53),[37] which (see Appendix XXIV) may have been capable of keeping range-rate and deflection approximately through a turn. In any case, when repeatedly altering course, the German Navy seems to have relied less on its rate instruments and clocks and more on its stereoscopic rangefinders. After Jutland, *Seydlitz* reported that:

> The electric clock was used only in the first part of the engagement [the Run to the South]; afterwards the movements of the ship were so frequent and sudden that regular shooting by electric clock was impossible. Firing was continued in connection with the...Basisgerat...in [the] forward gun control tower.[38]

Thus in these conditions the Germans used a form of rangefinder control.

Soon after the War began, the Royal Navy obtained and promulgated full details of German practices conducted in 1912-13. Between April and July 1913, nearly all the fully worked up battleships and battlecruisers carried out practices that are doubly noteworthy; the ranges were long: and the targets were three old battleships, moored in line.[39] Ranges were from 12,250 to 16,000 yards and rates reached 325 yards per minute. Some ships made only one hit from 36 rounds fired but, under less demanding conditions,

[35] *German Target Practice*, pp.5 and 11 (*op. cit.*).
[36] *Information from PoWs*, 1918, p.16 and Plate 3. von Hase, pp.79, 131 and 144. However, 'Mittlungs' has not been found in German dictionaries.
[37] von Hase, pp.131-3. Padfield, *Guns at Sea*, pp.228 and 250.
[38] *Seydlitz*, 'Experience', f.272.
[39] Admiralty War Staff, Intelligence Division, *Germany. Results of Firing Practices, 1912-13* December 1914, pp.14-15, 24-27, 34-5 and 44-53. ADM137/4799. Four *Nassaus*, four *Helgolands*, *Kaiser* and *Friedrich der Grosse*, *Moltke* and *von der Tann* took part in the practice.

others obtained over 10%. In addition, the rates of fire per gun equate to salvoes fired every 27-43 seconds, which suggests that the Germans broke into rapid fire as soon as they straddled their targets.

In 1921, *Derfflinger's* gunnery officer wrote that:

> Before the war no man in our navy had thought it possible to fight effectively at a range of over 150 hm. [16,250 yards] I can still remember...war games...in which on principle all shooting at more than 100 hm. [10,950 yards] was ruled out as ineffective.[40]

Nevertheless, when hostilities began, the German Navy had given most of their heavy ships an opportunity for practice at long ranges: and to observe the effects of their fire falling on and around actual ship targets. No doubt their greater insistence on spotting for shorts derived from this experience.

BRITISH RANGES AND PRACTICES

The Grand Fleet Battle Orders, first issued shortly after Jellicoe took command, assumed that:

> On a clear day and unless the enemy opens fire earlier, 13.5-inch guns ships will open deliberate fire at 15,000 yards, 12-inch gun ships at 13,000 yards.[41]

At least it was now possible for the ships of the Grand Fleet to begin practising at such ranges, firing initially at rocks and, from 1915, at battle-practice targets towed at up to 17,000 yards.[42] Unfortunately, the increase in ranges may not have been matched by widespread improvements in rangefinding. The Grand Fleet Order issued after the battle of the Dogger Bank had declared that, since so few ranges had been taken:

> The gun was, in fact, used as its own rangefinder and rate keeper.[43]

Frederic Dreyer, then still Captain of *Orion*, feared that, as a result, rangefinding practice would be neglected and, while he continued to encourage the training of rangetakers, he did not expect his efforts to have much impact outside his own 2nd Battle Squadron.

He also considered that:

[40] von Hase, p. 153.
[41] 'Extracts from Grand Fleet Battle Orders', 18 August 1914 in A. Temple Patterson (ed.), *The Jellicoe Papers, Volume I* (Navy Records Society, 1966) p.59.
[42] Frederic Dreyer, *The Sea Heritage* (London, 1955) pp.90-91 and 95. 'The Log of Captain F.C. Dreyer R.N. H.M.S. "Orion". 1914', DRYR 5/1, CC. Blackett, 'Naval Diary' (*op. cit.*) for 16 November 1915 and 31 January 1916. Unfortunately, no data have been found either on courses and speeds or the results obtained during such long-range practices.
[43] H. F. Memorandum, '66. Remarks on Action of 24th January 1915', 5 February 1915, p.18 in ADM 137/1943; there are some differences between this and the *GFG&TO*, 51 (*op. cit.*) with the same title.

> The unsupported Spotting of the Battle Cruisers does not seem to have been very good...[44]

In fact, it is clear that, in general, 'their reputation for gunnery was very very shaky indeed' and 'that the Battle Cruisers' shooting was rotten'.

> An officer posted to *Invincible* reported back to *Barham's* first-lieutenant that "he was shocked by the standard of efficiency he encountered." [45]

Undoubtedly, the battlecruisers, based in the Forth, found practice hard to get.[46] However, there also seems to have been a feeling in the Grand Fleet that they did not try hard enough.

> Ships from the Forth, visiting Scapa for gunnery drills, found that "the Battle Cruisers' name up here is mud, owing to the inefficiency of their gunnery and the general casualness and lack of concentration with which they appear to treat the war."[47]

In November 1915, Jellicoe wrote to Beatty:

> I am afraid you must have been very disappointed at *Lion* and *Tiger's* battle practice results. I can't understand how a control officer of experience could have made such a blunder as that made by *Lion's*....I fear the rapidity ideas were carried to excess in one case (*Queen Mary* I think). Also the RF operators were bad. It is most difficult for you to give them proper practice I know....

Beatty replied, with some complacency:

> Yes indeed it was a terrible disappointment the battle practice of *Lion* and *Tiger*....The other three were not bad but undoubtedly as you say we could do with much more practice at sea....I do not think you will be let down by the gunnery of the battle-cruisers when our day comes.
> ... on the subject of rapidity of fire [I] feel very strongly...and think we should endeavour to quicken up our firing...the Germans certainly *do* fire 5 to our 2...

Jellicoe's response was that:

> I...am very glad you think all will be well....
> I am all for rapidity of fire, but my only fear is that ships may break into rapid fire *too soon*, as *Queen Mary* I think did. It's all right even if not hitting *if short* but no use *if over*....[48]

Perhaps some of the battlecruisers improved before Jutland, but, on 7 May 1916, Beatty wrote to Jellicoe:

> I am sending you the results of the recent firings. The *Tiger's* was as usual unsatisfactory.

[44] That is, unsupported by rangefinding. Draft letter from Dreyer to unnamed recipient, 26 March 1915 in DRYR 1/3.
[45] Interview with Admiral Royer Dick (at Jutland, a midshipman in *Barham*) and papers of Rear-Admiral S Tillard cited in Gordon, *Rules of the Game.* (*op. cit.*) pp.30 and 51. The second quotation is from 'The Diaries of Stephen King-Hall' in L King-Hall (ed.) *Sea Saga* (London, 1935) p.436.
[46] Chatfield, *Navy and Defence* (*op. cit.*) p.138.
[47] S King-Hall quoted by Gordon, *Rules of the Game*, p.30.
[48] Jellicoe to Beatty, 18 and 23 November 1915 and Beatty to Jellicoe, 21 November 1915: in *Jellicoe Papers I* (*op. cit.*) pp. 188-9.

Although Beatty was at last considering a replacement, Captain Pelly was still in command on 31 May 1916.[49]

THE BATTLE OF JUTLAND[50]

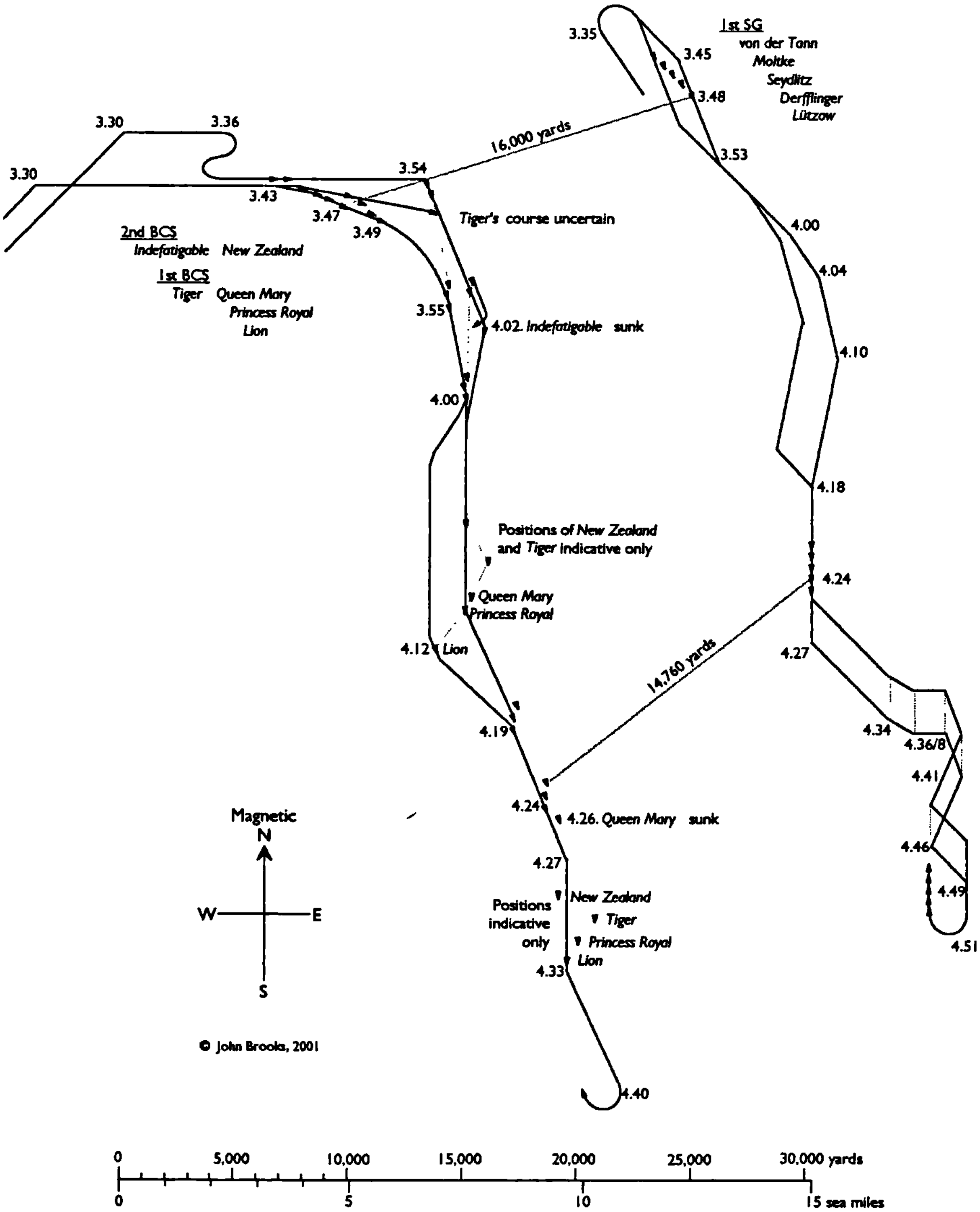
In his secret despatch, Jellicoe wrote of the opening action, the Run to the South:

> The disturbing feature of the battle-Cruiser action is...that five German battle-cruisers engaging six British vessels of this class, supported after the first twenty minutes, although at great range, by...four battle ships of the QUEEN ELIZABETH class, were yet able to sink the QUEEN MARY and INDEFATIGABLE...the result cannot be other than unpalatable.[51]

John Campbell's analysis of the engagement indicates that, for every hit made by Beatty's ships (the 1st and 2nd Battle Cruiser Squadrons), Hipper's battlecruisers made almost four in return.[52] The purpose of this chapter is to describe the tactical details of the action and the conditions under which it was fought. If these external factors can be properly understood, then, in the final chapter, it should be possible to determine whether the fire control tables in Beatty's battlecruisers contributed significantly to the failure of their gunnery.

Despite many uncertainties, Fig. 6.1 attempts to chart the courses of the two sides during both phases of the Run to the South. It differs in many details from the charts in recent books, which are usually similar to Marder's.[53] The principal course changes are described in the text, with substantiating detail in the appendices, especially the notes in Appendix XXVI.

[49] Beatty to Jellicoe, 7 May 1916 in *Beatty Papers I*, p.308.
[50] Two recent accounts of the battle are Gordon, *Rules of the Game*, which is particularly concerned with British command and signalling: and V E Tarrant. *Jutland. The German Perspective* (London, 1997), which relies heavily on the German Official History. Arthur J. Marder, *From the Dreadnought to Scapa Flow Vol.III, Jutland and After* (Oxford, 1978) contains a useful account, valuable judgements and comprehensive charts.
[51] C.-in-C. Home Fleets, Action with the German High Sea Fleet 31st May - 1st June 1916 (Secret Report), 18 June 1916 in ADM 137/301. Also in *Jellicoe Papers I*, p.286.
[52] N J M Campbell, *Jutland. An analysis of the fighting* (London, 1986) pp.78, 94 and 354-5. This work is an indispensable source for the damage caused by hits on both sides. It also provides the only available detailed breakdown of when the hits were made and by what ships. Unfortunately, it lacks footnotes and conclusions are often stated without explanations. Thus some of its detailed deductions are questionable: see Gordon, *Rules of the Game* p.413 and later in this chapter.
[53] Compare *FDSF III*, Charts 4 and 5 with Campbell, *Analysis*, pp.44-5 and 57 and Tarrant, *German Perspective*, pp.79, 82, 87 and 95.



Notes

1. Times of course changes are taken, if available, from the British and German records of signals.
2. When firing began, German times were about one minute fast.
3. Beatty ordered 24 knots at 3.35. Hipper ordered 18 knots at 3.40 and 23 knots at 4.12.

FIG. 6.1: JUTLAND: THE RUN TO THE SOUTH (BATTLECRUISERS)

THE RUN TO THE SOUTH: FIRST PHASE

The opposing battlecruisers forces sighted each other between 3.15 and 3.20. Beatty's ships were headed NE;[54] *Lion* led the rest of the 1BCS (in order *Princess Royal*, *Queen Mary* and *Tiger*) but Beatty had taken no steps to concentrate his squadrons. The four battleships of the 5th Battle Squadron were some 7 miles on his port beam, a position from which they were unable to take part in the first phase of the coming engagement.[55] The 2BCS (*New Zealand* followed by *Indefatigable*) were about 3 miles off *Lion's* starboard bow, closest to Hipper's 1st Scouting Group (*Lützow* leading *Derfflinger*, *Seydlitz*, *Moltke* and *von der Tann* in line astern) steaming NWbyN.[56] Between 3.25 and 3.30, the 1SG were sighted from *Lion* at a range estimated as 23,000 yards.[57] Thus, at that time, there does not seem to have been much difference between the best visibility from the two sides.

> ...the weather was misty in patches, the visibility varying from 12 to 6 miles; wind west, force 3; sea calm.[58]

At 3.30, Beatty turned his squadrons together to E, and only then finally decided that the 2BCS (his weakest ships) should prolong the line astern;[59] by means of two rapid 16-point turns, Rear-Admiral Pakenham completed the manoeuvre by about 3.42.[60] Meanwhile, with his line of retreat threatened, at *3.34*, Hipper had ordered a turn away in succession of 15 points onto course SE. By *3.39*, *Lützow* had probably steadied on the new course when he called for a speed of 18 knots, having already ordered a distribution

[54] Tarrant, *German Perspective* (*op. cit.*) p.69. Appendix II, 'Record of Messages bearing on the Operation' in *Battle of Jutland. Official Despatches with Appendices* (London, 1920) pp.443-452; the signals of the forces commanded by Beatty are in Appendix XXVII.
In this account, all courses are given in compass points relative to magnetic North, while times are GMT post-meridiem

[55] Gordon, *Rules of the Game*, especially Chapter 6 and *FDSF III* (*op. cit.*) pp.57-62 and Chart 4.

[56] Unless stated otherwise, German courses and times in this account are based on Tarrant, *German Perspective*, Appendix 10, 'Summary of the More Important Wireless Messages and Visual Signals Relating to the Battle of Jutland'; the 1SG signals are also given here in Appendix XXVII, where the times have been advanced by one hour to conform with GMT.

[57] 'Record of Events during Action of May 31st compiled from Records kept in Control Position and Transmitting Station. H.M.S. Lion' in BTY 6/6. British 'Record of Messages'.

[58] 'Narrative of...the Gunnery Officer of H.M.S. "Tiger"' in H W Fawcett and G W W Hooper, *The Fighting at Jutland* (London, 1921) p.423. See also Captain, *New Zealand* to RAC, 2BCS, 'Report of Action of 31st May 1916', 2 June 1916 in ADM 137/302.

[59] British 'Record of Messages' (*op. cit.*). 'Battle of 31st May: Narrative of Events' in 'Action with the German High Sea Fleet, 31st May - 1st June 1916. VABCFs Personal Records', BTY 6/3, NMM (partly reproduced in Appendix XXVIII).

[60] The British 'Record of Messages' times Pakenham's first order at 3.36 while the chart 'Battle of Jutland. Battle Cruiser Action First Phase 2 p.m. to 3.40 p.m. May 31st 1916', BTY 24/49 suggests that *New Zealand* turned into line no earlier than 3.42; see Appendix XXVI, Note 1 (XXVI-1).

of fire from the left (XXVI-2). Between the leading ships, the range was, therefore, now closing at almost 550 yds/min (XXVI-3). Subsequently, the German battlecruisers made only one more course alteration, of 2 points together to SSE at *3.44*, 'to close the enemy more rapidly'. When they opened fire at *3.47*, their targets and ranges were:

Lützow	16,800 yards	*Lion*
Derfflinger	16,400 yards	*Princess Royal*
Seydlitz	16,400 yards	*Queen Mary*
Moltke	15,500 yards	*Tiger*
von der Tann	17,700 yards	*Indefatigable*[61]

Thus *von der Tann* missed out *New Zealand* (Fig. 6.2); perhaps she had found it difficult to keep on one target while the 2BCS twice reversed course.

Once the 2BCS had hauled into line, Beatty made his only fire distribution signal, for the leading pair (*Lion* and *Princess Royal*) to concentrate (on *Lützow*). A minute earlier, a flag signal ordered the formation of a line of bearing NW, but this was followed

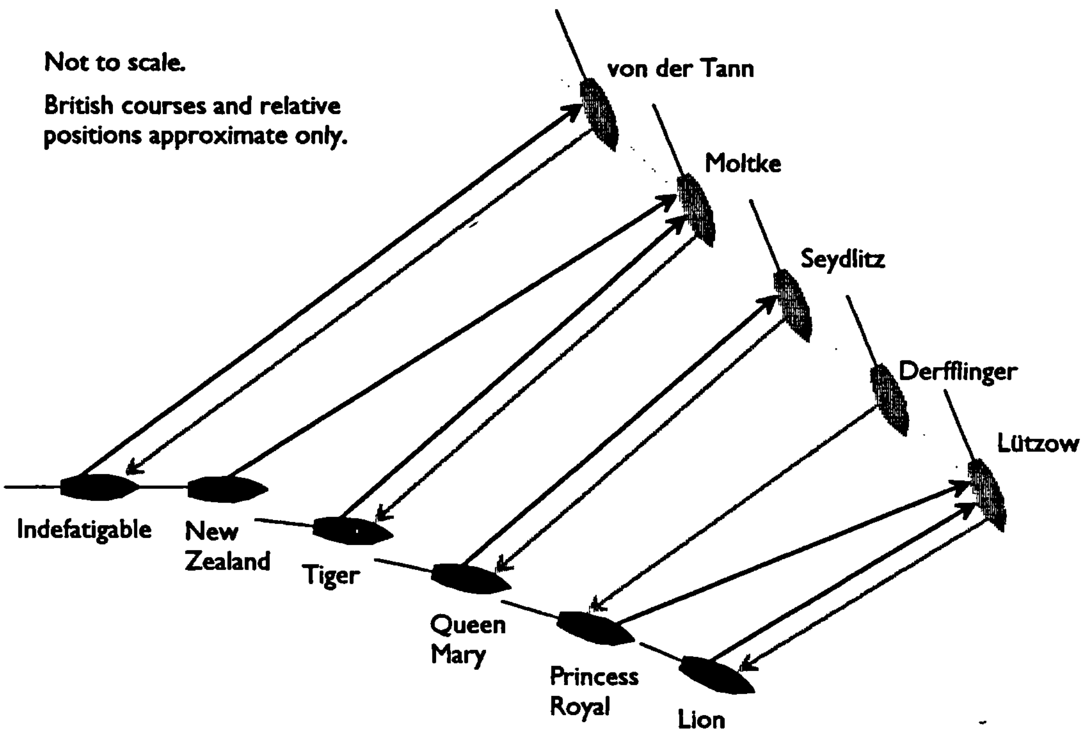


FIG. 6.2: RUN TO THE SOUTH: INITIAL FIRE DISTRIBUTION

[61] Admiralty, Naval Staff, *The Battle of Jutland (The German Official Account)*, from *Der Krieg zur See, 1914-1918, North Sea, Volume V* by Captain O Groos, trans. Lieut.-Commander W T Bagot, RN, May 1926, pp.57-8, AL.

(either immediately or at 3.47) by a second signal, to turn together to ESE.[62] The first signal alone would have resulted in all the ships astern of *Lion* turning to port, further increasing the rate and ensuring that their after turrets could not bear. Thus both signals were probably intended to be read and acted upon together by turns to starboard; however, since the signals were sent separately, perhaps with as much as two minutes between them, they could well have created confusion in the British line (XXVI-4). Even if they were correctly interpreted, only the leading ships turned to the course ESE or close to it,[63] alterations which were urgently needed to reduce the rate and open the turret training angles. And, unfortunately, the move had already been countered by Hipper's turn to SSE, which kept the range between the flagships closing at 570 yds/min (XXVI-3).

Lion and *Princess Royal* returned the German fire immediately (both ships timed their first salvoes at 3.47½)[64] but *Tiger* did not open until a minute or so later, with *Queen Mary* about two minutes later still.[65] *New Zealand* opened at *3.51*.[66] The targets and initial ranges were as follows.

Lion	18,500 yards	*Lützow*
Princess Royal	16,000 yards	*Lützow*
Queen Mary	~17,000 yards	*Seydlitz*
Tiger	~18,500 yards	*Moltke*
New Zealand	18,100 yards	*Moltke*
Indefatigable	?	*von der Tann*[67]

[62] Compare the British 'Record of Messages' and Beatty's Personal Narrative (*op. cit.*). *Lion's* 'Record of Events' (*op. cit.*) states that she altered course to starboard at 3.43 (one point) and 3.46 (unspecified).
[63] This interpretation of the signals is largely based on advice concerning fleetwork in general and line-of-bearing manoeuvres from Captain Peter Grindal, RN, whose comments on the previous draft of this chapter have been most helpful.
[64] *Lion's* 'Record of Events'. 'H.M.S. "PRINCESS ROYAL", Fore T.S. Record of Action, 31st May 1916' in ADM 116/1487.
[65] H.M.S. "TIGER", Gunnery Records during Action of 31st May 1916 in ADM 116/1487. Captain Pelly to VAC BCF, 6 June 1916 and Report by Midshipman J L Storey of *Queen Mary*, 3 June 1916, both in ADM 137/302 (the latter states that *Queen Mary* began firing at 3.53).
[66] H.M.S. "NEW ZEALAND", 'Action with German Fleet 31st May 1916. Record of Ranges, Rates, etc. Compiled from Transmitting Station & Control Top Records' in ADM 116/1487 times her first salvo at 3.57. However, Appendix I to 'Second Battle Cruiser Squadron. Report on Action of 31st May 1916', 3 June 1916 in ADM 137/302 gives the time for *Lion's* opening fire as 3.54, so it has been assumed that New Zealand's times were six minutes fast. See also Campbell, *Analysis* (*op. cit.*) pp.39 and 48. Her adjusted times are shown here in italics.
[67] *Lion's* 'Record of Events'. *Princess Royal*, 'Record of Action' *Tiger*, 'Gunnery Records'. *New Zealand*, 'Record of Ranges'. Storey, 'Report' (all *op. cit.*).

Thus Beatty's ships were disadvantaged fourfold. Since the actual range was about 16,000 yards,[68] at least four opened with ranges that were far too high. They were attempting to reform their line under fire in accordance with the muddled signals from *Lion*. The after turrets of the 2BCS, and probably of *Tiger* and *Queen Mary*, could not bear (XXVI-5). And both *Queen Mary* and *Tiger* were shooting at their opposite numbers, so *Derfflinger* was not under fire.

Beatty's despatch appears to be deliberately misleading about his conduct of the approach; nonetheless, it establishes that smoke interference was a problem during the approach - and that the general visibility was not.[69]

> At 3.30 p.m. I increased speed to 25 knots and formed the Line of Battle, the 2nd Battle Cruiser Squadron forming astern of the 1st Battle Cruiser Squadron....I turned to E.S.E., slightly converging on the enemy, who were now at a range of 23,000 yards, and formed the ships on a line of bearing to clear the smoke....The visibility at this time was good, the sun behind us and the wind S.E.[70]

However, all other sources describe the wind as a light Westerly breeze, though they differ somewhat in the extent and timing of a shift from NW to SW (XXVI-6).[71] This wind would have piled up the smoke astern while on course E, and carried it onto the engaged side, especially after the turns to ESE; on either course, the solution was a line of bearing NW (XXVI-4). Even before it was formed, *Lion*, at the head of the line, should not have been troubled by smoke, while her smoke evidently did not affect *Princess Royal*; the second British ship had no difficulty in making out '5 Enemy Battle Cruisers in sight' at 3.34.45, and, at 3.42, she chose the 'Right hand ship ("Lutzow" class)' as her target.[72] Her initial range was by far the most accurate of Beatty's ships: while her rate of -400 yds/min. was the most accurate known from either side.[73]

> I think that at this time all the battle cruisers except "P.R." had underestimated the rate; we had [in *Tiger*].[74]

[68] Campbell, *Analysis*, p.39. Julian Corbett, *History of the Great War based on Official Documents..Naval Operations Volume III* (London, 1923) p.334. Chatfield, *Navy and Defence*, p.142.

[69] 'The visibility was good but not abnormal' although, after opening fire: 'They had the advantage of light...' Midshipman N G Garnon-Williams, stationed in *Lion's* conning tower. Papers of Captain N G Garnon-Williams, 85/26/1, IWM.

[70] VAC BCF to C.-in-C. Grand Fleet, 12 June 1916 in *Beatty Papers I*, p.326: also in ADM 137/302.

[71] von Hase, pp.153-4. Appendix III, 'Report by the Commander-in-Chief of the German High Sea Fleet on the Battle of Jutland, 4 July 1916' in Jutland, *Official Despatches* (*op. cit.*). 'Narrative from H.M.S. "Indomitable"' p.243 and *Tiger's* Gunnery Officer (*op. cit.*) p.423 in *Fighting at Jutland* (*op. cit.*). Admiral Pelly, *300,000 Sea Miles* (London, 1938) p.165. *New Zealand* to RAC 2BCS (*op. cit.*).

[72] *Princess Royal*, 'Record of Action').

[73] 'Narrative from Officers of H.M.S. "Princess Royal" in *Fighting at Jutland*, p.18.

[74] *Tiger's* Gunnery Officer, p.421. *New Zealand*, 'Record of Ranges' gives -200 yds/min. *Derfflinger's* opening rate was -220 yds/min: von Hase, p.145-7.

In marked contrast, *Tiger's* 'Gunnery Record' does not even begin until 3.44 with:

G.M.T.	Gun Range.	Object	Remarks
3.44			Enemy reported in sight from "Lion".
3.45			Sighted enemy B.C.S. apparently 3, "Derflinger" [*sic*], "Seydlitz" amd "Moltke".
3.48			Enemy opened fire.
3.50			"Lion" opened fire.
3.51	18.500	4th ship from right, "Seydlitz" class	Considerable interference from own T.B.Ds' smoke.

Even after *Tiger* opened fire:

> The top reported that the funnel smoke of our battle cruisers ahead made their view very bad....[75]

Information about *Queen Mary* is necessarily scarce. Though next ahead from *Tiger*, she opened fire later, and, although she was regarded as the crack gunnery ship of the BCF,[76] her initial range was probably a thousand yards too high. Furthermore, like *Tiger*, she fired at her opposite number in the German line. Yet (subject to ensuring that no ship was left unfired at) Grand Fleet orders emphasised the importance, if numbers permitted, of concentrating on an enemy's leading ship or ships;[77] this was the distribution scheme assumed, without orders, by *Princess Royal* at 3.42, ordered from *Lion* at 3.46 and adopted by the 2BCS. It seems unlikely that *Queen Mary* and *Tiger* would have chosen differently: and, probably, they did not in fact do so. If *Queen Mary*, like *Tiger*, could not at first see *Lützow*, *Seydlitz* and *Moltke* would have appeared to have been their correct targets. Evidently, by the time of her first salvo, the mistake was apparent in *Tiger*, but, with smoke interference from both battlecruisers and destroyers, there was neither time nor opportunity for either ship to change target. Thus Beatty's delay in reforming his line 'to clear the smoke' had particularly bad effects on these two ships. Not only did they select the wrong targets, but they were able to begin ranging and plotting only a few minutes (three in the case of *Tiger*) before their opponents opened fire, while, even then, they were

[75] *Tiger*, 'Gunnery Records' and *Tiger's* Gunnery Officer, pp.423-4.
[76] Midshipman G M Eady, 'Account of Jutland' in 'Life in the Battle Cruiser Fleet 1916' in papers of Commander G M Eady, 86/58/1, IWM.
[77] Pelly to Beatty, 31 January 1915 (summarised to justify *Tiger's* firing for a time at the leading enemy ship during the Battle of the Dogger Bank). See also Beatty memorandum of 17 July 1913. Both in *Beatty Papers I*, pp.75 and 213-4.

still not free from smoke interference. It is not surprising that their opening ranges and rates were inaccurate.

Since *New Zealand's* Captain was 'rather impressed by the little smoke interference there was',[78] the 2BCS must have come into line on *Tiger's* port quarter. However, their violent manoeuvres created conditions of rapidly changing bearings, heel and vibration which made ranging impossible; it was not until *3.45* that *New Zealand*: 'Commenced ranging on the 4th ship from the right'.[79] With the 1BCS making 24 knots, the 2BCS also had to recover the speed lost in the turns; when she opened fire, her engines were making over 300 revolutions per minute, more than she had managed at the Dogger Bank,[80] so all her rangefinders must have been subjected to considerable vibration. Thus the ranging of the 2BCS was disrupted by the struggle both to join and to stay in line.[81]

Lion's rangetakers had none of the difficulties experienced by those in the four rear ships, yet they failed conspicuously to match the standard set by *Princess Royal*. *Lion's* TS record contains only two rangefinder ranges from the period of the approach: 20,000 yards at 3.42 and 18,500 yards at 3.46. From the calculated rates, it can be estimated that they were too high by, respectively, 900 and 1,600 yards (XXVI-3). Yet her TS did not even accept the implied rate of -375 yds/min. When fire was opened at 3.47½, the rate in use was only -150 yds/min: while the opening range was still 18,500 yards, as though, since 3.46, there had been no rate at all. And the other recorded rates suggest that, throughout the approach, their estimate of enemy course was insufficiently converging by as much as 4 points.[82] It appears that, despite Beatty's reassurances to Jellicoe, the whole fire control organisation of his flagship was no more efficient than it had been during the practices of late 1915.

Somehow, Beatty himself seems to have been aware of the German course, since he reported it by wireless to Jellicoe at 3.45 as S 55° E; this was barely 3° different from their SE'ly course held until a minute before (XXVI-8). However, he may not have been aware of the serious gunnery implications. Admiral Goodenough, though an admirer,

[78] *New Zealand* to RAC 2BCS.
[79] *New Zealand*, 'Record of Ranges'.
[80] Eady, 'With the Battle-Cruiser-Fleet at Jutland' in 'Life in the BCF' (*op. cit.*). Eady claimed 327 rpm. and 29.7 knots but these figures must be exaggerated. On trial, *New Zealand* managed 26.39 knots at 300 rpm: John Roberts, *Battlecruisers* (London, 1997) p.80.
[81] For the effects of vibration at high speed, see Chatfield, *Navy and Defence*, p.109.
[82] *Lion*, 'Record of Events'. Note XXVI-7.

admitted that the pre-eminence of 'that ardent spirit Lord Beatty' did not derive from 'great professional knowledge, certainly not of gun or torpedo'.[83] Unfortunately, at this critical moment, Beatty was unable to turn to his flag-captain, on whose gunnery expertise he customarily relied.[84] Chatfield recalled:

> I was on the compass platform...Beatty remained for a time on his own bridge...with [his staff]. I wanted him to come on the compass platform and sent a message to Seymour, telling him to advise Beatty that the range was closing rapidly and that we ought almost at once to be opening fire....But I could get no reply, the Vice-Admiral was engaged in an important message to the Commander-in-Chief. 18,000 [*sic*] yards. I told Longhurst [the gunnery commander] to be ready to open fire immediately.[85]

Thus Chatfield implies that Beatty was preoccupied with signalling and had not yet realised that they were already within the range at which they must expect a rapid and accurate fire from the German ships. Another possibility is that Beatty deliberately chose to ignore Chatfield's conclusions after the Dogger Bank and to follow his own intention to press in to 12-14,000 yards: in which case their separation denied Chatfield a final opportunity to warn against such a dangerous tactic.

Whatever the explanation, Hipper was in no doubt about the consequences of Beatty's headlong approach.

> The fact that the English Battlecruisers, [possibly] on account of bad light conditions or perhaps forming line of Battle too late, delayed opening fire, allowed us too to withhold our fire until the enemy was in effective gun range (15,000-16,000 yards). The possibility of obtaining a rapid gunnery superiority...is principally to be attributed to this delay in opening fire which compelled the enemy to remain a longer time within effective gun range.[86]

The light now favoured the Germans, especially for spotting, since they were 'against a dark grey background, whilst we were silhouetted against the Western sky'.[87] The effects of the fire from the 1SG were quickly felt; by 3.52, both *Lion* and *Tiger* had been hit twice.[88] Hipper held his course SSE until *3.53*, which brought the range down to less than 13,000 yards; he then probably turned *Lützow* away to SE before ordering his ships to follow in her wake.[89] Even before she was hit, at 3.49, *Lion* began a series of unsignalled

[83] William Goodenough, *A Rough Record* (London, 1943) p.91.
[84] Roskill, *Beatty*, p.131.
[85] Chatfield, *Navy and Defence*, pp.141-2.
[86] Hipper to Scheer, 'Lessons from the Skaggerak Battle' in DRYR 6/10 and ADM 137/1644.
[87] 'Diaries of Stepen King-Hall' (*op. cit.*) p.451. See also Chatfield, *Navy and Defence*, p.141.
[88] Campbell, *Analysis*, pp.40-1, 67 and 73-4.
[89] German 'Summary of Messages'. von Hase, p.152. 'German Plan IV. Battle Cruiser Action', BTY 24/37. Note XXVI-11.

turns away;[90] thus there was no possibility of even the 1BCS completing the formation of a regular line of bearing. By 3.55, *Lion* had steadied on a course SbyE, which she held until 4.00; thus, after 3.55, the range between the leading ships was opening at a rate of 460 yds/min. or even more.[91]

Without signals from the flagship, Beatty's other battlecruisers were left as best they could to follow his movements. *Princess Royal* also 'gradually altered to southward', but she seems to have got into *Lion's* smoke, as well as being subjected to *Derfflinger's* undisturbed fire; thus she was unable to make anything of her accurate opening range and rate before her fire was badly disrupted at 3.56 by a hit on her Argo rangefinder tower.[92] *Queen Mary* made the first British hit, on *Seydlitz*, at 3.55, while her second hit, at 3.57, burned out the after superfiring turret;[93] she evidently had few problems with smoke from ahead, which suggests that she made a wider turn than *Princess Royal*. *Queen Mary's* survivors did not recall any hits on their ship until much later,[94] but *Tiger* was hit repeatedly by *Moltke*, after which Q and X turrets were incapable of accurate fire for the rest of the battle.[95] Also, *Tiger's* gun ranges continued downwards after 3.55 to reach a minimum of 10,500 yards just after 4 o'clock, while *Moltke's* ranges are also surprisingly low about that time.[96] All this suggests that, until then, *Tiger's* courses were more Easterly than those of the rest of the 1BCS (Note XXVI-12).

At the rear of the British line, the 2BCS was still headed E at 25 knots when firing began and remained on this course until *3.54*, when they turned six points to SSE[97]. These courses kept them well clear of smoke from the 1BCS to starboard: while the turn altered the rate from almost -800 yds/min. closing to under +300 yds/min. opening and allowed the after turrets to bear (XXVI-13). Their large turn probably disrupted ranging

[90] The British 'Record of Messages' contains no course signals from Beatty between 3.45 and 4.40.
[91] 'Track of BCF II.0 P.M. to IX.24 P.M. 31/5/16' (undated but apparently enclosed with BCF reports) in 'Jutland. Plans, Diagrams, Track, Charts, Photographs, &c', ADM 137/303; also in ADM 137/2147. 'Battle of Jutland. Battle Cruiser Action. Second Phase 3.40 to 5 P.M., May 31st 1916', BTY 24/51. *Lion*, 'Record of Events'. Notes XXVI-9, -10 and -11.
[92] *Princess Royal*, 'Record of Action'. Captain Cowan to RAC 1BCS and 'Notes on Action' with RAC 1BCS to VAC in ADM 137/302. British 'Record of Messages' for 3.55. Notes XXVI-10 and -11.
[93] Campbell, *Analysis*, pp. 41 and 80-3.
[94] M W Williams, 'The Loss of HMS Queen Mary at Jutland' in D McLean and A Preston (eds.) *Warship 1996* (London, 1996), p.122.
[95] Campbell, *Analysis*, pp.71-5. For the effects of hits on Q and X turrets, see Lt. Cmdr. Macnamara to Captain Pelly, 4 June 1916 in BTY 6/6.
[96] *Tiger*, 'Gunnery Records'. *German Official Account* (*op. cit.*) p.62.
[97] 'Second BCS Report'. The small 'Tracing of track followed by Second Battle Cruiser Squadron...' (originally enclosed with this report and now in ADM 137/303) confirms the time but shows a course of SEbyS.

and aiming and added to the control problems due to their large opening errors; neither *New Zealand* nor *Indefatigable* made any hits either before or after *3.54*.[98] However, the initial high rate reduced the range to a minimum of 13,450 yards, close enough for *von der Tann* to bring her secondary 5.9-inch guns into action.[99]

At 4.00, the 1SG was ordered to turn together to SEbyS;[100] if they were already headed SE, this would have been a turn towards. At the same nominal time, both flagships found each other's range. *Lützow* was hit twice while a single hit wrecked *Lion's* Q turret. Her TS record of target bearings (XXVI-10) shows that, at this moment, *Lion* turned away rapidly by almost three points so that, at least momentarily, A and B turrets were not bearing: though, by 4.04, despite three more hits, she had been brought back onto a new course S.[101] *Lion's* sudden swing to starboard was confirmed by her Captain.

> It was at this moment [after Q turret had been knocked out], seeing that the range was decreasing and not wishing to let it do so, I told Commander Strutt to steer 5 degrees to starboard. Strutt gave the order. The Chief Quartermaster, however, misheard it as ordering him to give the ship 5 degrees of port helm. I suddenly saw the ship swinging off to starboard rapidly and had to bring her back and increase speed to resume our station. The ships astern, having seen the large flame shooting up, thought we were steering off because of the damage!
> At 4.25, soon after we resumed our position ahead of the "Princess Royal"...the "Queen Mary"...blew up exactly as had "Indefatigable".[102]

Meanwhile, at about 4.02, *von der Tann* succeeded in straddling *Indefatigable* with two salvoes in quick succession; at least two 11-inch shells from each were observed to hit and, shortly after the second salvo, *Indefatigable* blew up, vanishing entirely under a great pall of black smoke.[103]

As the two lines drew apart at the end of this first phase of the Run to the South:

> From the *Lützow* it appeared about this time [*c*.4.05] as if the British flagship hauled out of line, with a list of 10 degrees to starboard; she seemed to disappear at times behind the other vessels wrapped in a thick pall of smoke....At times the enemy's fire ceased

[98] Since *Moltke* was the target of *Tiger* as well as *New Zealand*, each ship's fall of shot may well have confused the other's spotting.
[99] *German Official Account*, p.61.
[100] German 'Summary of Messages'.
[101] Campbell, *Analysis*, pp.41-2, 64-9 and 78-9. *Lion*, 'Record of Events'. Beatty's Personal Narrative. 'Track of BCF' (which shows a turn from SbyE to S at 4.00).
[102] Chatfield, *Navy and Defence*, p.143. However, the ranges in *Lion's* Record of Events were increasing (XVI-10). In a letter to Keyes dated January 1923 (in KEYES/15, BL), Chatfield gave a different and more likely explanation of what may have been, at first, a small turn to throw out the enemy fire: 'Lion actually made one considerable swing to Starboard about 2 Pts. Owing to Comd (N) saying Port 5 and then forgetting he had done so'. This is a common error (Captain Grindal).
[103] Campbell, *Analysis*, pp.60-2. Note XXVI-14.

> altogether and the tactical cohesion of the British line appeared to be seriously shaken.[104]

Beatty's ships had made only six hits, whereas they had received at least 22 in return.[105] The consequences of Beatty's tactics, aggravated by an unfavourable position for spotting, are amply sufficient to explain the rapid loss of gunnery superiority. His approach was too steep to allow enough time: firstly to get the 2nd BCS into line astern: secondly to form the line-of-bearing necessary to avoid mutual smoke interference: thirdly to allow all ships to range and plot in favourable circumstances: and fourthly to keep the enemy at the long ranges which exploited the advantages conferred by the heavier guns of the 1st BCS. Instead, when they came under fire, the British battlecruisers were already within their opponents' effective range: they were still trying to reform their line in accordance with *Lion's* confusing signals: some ships were still hampered by smoke: not all their turrets were bearing: only one ship had obtained an accurate opening range and rate: and, despite their numerical superiority, one of their opponents was not even under fire.

THE RUN TO THE SOUTH: SECOND PHASE

After the sinking of *Indefatigable*, Hipper turned his ships together at 4.04 to SbyE but his leading ships were soon obliged to cease firing as the range continued to increase. Between 4.07 and 4.10, he again altered together to the slightly converging course of SbyW. The 1SG increased speed to 23 knots at 4.12, while *Lützow* probably altered one point away to South before, at 4.18, Hipper ordered his other ships to follow in his wake. They then held a steady course until 4.27.[106]

By 4.10, Beatty's ships were all on course S with *Lion* (as Chatfield confirms) still out of line to starboard of *Princess Royal* and *Queen Mary*. *Tiger* and *New Zealand* were further astern, with, for a time, *Tiger* nearer to the enemy. *Lion* and *Queen Mary* (as far as can be known) were continuing to fire steadily at their opposite numbers, while *New Zealand* was now firing at *von der Tann*;[107] *Tiger* was attempting to keep her guns on the *Moltke*, but, due to her damaged turrets and a suspect director, she could only fire her shots in ones and

[104] *German Official Account*, pp.61-2.
[105] Campbell, *Analysis*, Chapter 5. The ricochets which struck *Lion* and *Tiger* (the latter 'probably hit in the first 10 minutes') - pp.67 and 75 - have not been included in German total.
[106] German 'Summary of Messages'. *German Official Account*, p.63. 'German Plan IV. Battle Cruiser Action', BTY 24/37. The last two time the turn to SbyW at 4.10. The chart shows a course S after 4.18.
[107] *Lion's* courses from 'BCF Track Chart' and inferred from target bearings in *Lion*, 'Record of Events'. *New Zealand*, 'Record of Ranges'. Notes XXVI-10 and -15.

twos, while some of these were probably aimed at *Seydlitz*.[108] Between 3.55.15 and 4.15.28, *Princess Royal's* record contains only one range (19,100 yards at 4.06.50) and no indication that she changed target;[109] however, von Hase of *Derfflinger* implies that she had done so even before *Indefatigable* was destroyed, while, even if this was not the case, it is most unlikely that *Princess Royal* left her opposite number undisturbed after the British line was reduced to five ships.[110]

At about ten past four, the 5BS were at last able to open fire, initially at *von der Tann*, which was hit almost immediately at a range of 19,000 yards; they were soon able to concentrate 'a regular hail of 15-inch projectiles' on *Moltke* as well.[111] Beatty then turned *Lion* to a course SE, which, from 4.12, began to close the range at about -710 yds/min. Although apparently without the aid of signals from the flagship, Admiral Brock in *Princess Royal* responded appropriately by altering to SSE; thus, by 4.19-20, *Lion* had drawn ahead, when she too turned SSE. By then, Hipper had also altered away to South, so the calculated rate works out at just over -250 yds/min.[112] During this new approach by the British ships, *Lützow* was hit twice and *Seydlitz* once, the latter by *Queen Mary* at 4.17, when the ranges were probably still about 18,000 yards.[113] However, as the range fell, at 4.15-17 the 1SG were able to reopen fire.[114]

> Once more the "Lion" was covered by the German fire, receiving several hits and, due partly to a still fiercely burning fire from an earlier hit, she became so enveloped in smoke and fumes as to be at times invisible from ships astern of the "Lützow".[115]

von Hase confirms that *Lion* could not be seen from *Derfflinger*, *Lützow's* next astern, though the reason he gives is somewhat different.

> At [4.17] I again engaged the second battlecruiser from the left. I was under the impression that it was the same ship as I had engaged before, the *Princess Royal*. Actually, however, it was the *Queen Mary*....this was due to the fact that, just as I was finding my target, Admiral Beatty's flagship, the *Lion*, was obliged to fall out of the enemy line for a time, and, owing to the heavy smoke covering the enemy line, could not be seen by us.

[108] *Tiger*, 'Gunnery Records'. *Tiger's* Gunnery Officer, pp.424-5.
[109] *Princess Royal*, 'Record of Action'.
[110] von Hase, p.150. However, Campbell, *Analysis*, p.79 assumes that *Princess Royal* was still firing at *Lützow*.
[111] Captain A W Craig (*Barham*), 'Report of Action of 31st May 1916' in ADM 137/302. Beatty's Personal Narrative and VAC BCF to C.-in-C. (*op. cit.*) p.326. *German Official Account*, p.64 .
[112] 'Track of BCF'. Beatty's Personal Narrative. *Lion*, 'Record of Events'. 'Officers of *Princess Royal*' (*op. cit.*) p.19. Note XXVI-15. For rates, see Chapter 2.
[113] Campbell, *Analysis*, pp.48 and 79-80. As explained above and in XXVI-15, the two hits on *Lützow* at about 4.15 were probably by *Lion*, not *Princess Royal*.
[114] von Hase, p.152. *Lion*, 'Record of Events'.
[115] *German Official Account*, p.66.

von Hase cannot be correct about the time at which *Lion* fell out of line but, nonetheless, she had still not regained her proper position at the head of the line and remained hidden from *Derfflinger*. Unfortunately, *Seydlitz* did not make the same mistake in identifying her target, so both German ships concentrated on *Queen Mary*.[116]

Beatty's ships remained in the windward position, from which smoke interference would again be a problem if they did not form a line of bearing inclined towards the enemy. In addition, they now had the worst of the visibility. In the first version of his despatch, Beatty wrote that:

> The visibility to the North Eastward had become considerably reduced and the outline of the ships very indistinct. This, no doubt was largely due to the constant use of smoke balls or charges by the enemy, under cover of which they were continually altering course or zig-zagging.

The reference to imaginary smoke balls was omitted from the published version of his despatch, while the only German ships that needed to zig-zag were those under the hot fire from the 5BS. Nevertheless, there is no reason to doubt the deterioration in visibility, particularly for the British battlecruisers.[117] *Lion's* high ranges (she recorded rangefinder ranges of 23,000 yards at 4.12 and 21,000 yards at 4.16) are explicable, at least to some extent, by her position out of line and the increased difficulty in rangetaking. Nonetheless, they fell at an average rate of -525 yds/min., not much less than the calculated value. Unfortunately, this trend was largely disregarded; the rates in use just before and after the turn to SSE were still only -200 and -150 yds/min., though the small rate reduction indicates that *Lion's* fire controllers were just beginning to recognise their mistake.[118] Unlike the first approach, nothing suggests that Beatty had any more accurate information to guide him: while, from the ranges known for his other ships between 4.15 and 4.20, it appears that no one on the British side realised the extent to which they were converging on the 1SG.[119] Perhaps they had been misled by Hipper's change of course and formation at 4.18. After the three earlier hits on *Lützow* and *Seydlitz*, their fire probably had no further effect, since it is much more likely that the two hits at 4.20 and 4.23 on *von der Tann* were made by the 5BS rather than *Tiger*.[120] Thus, although *Princess*

[116] von Hase, pp.154 and 159.
[117] VAC BCF to C.-in-C. pp.326 and 328. Extract from Beatty's report in 'Jellicoe's Despatch...as published in...the *London Gazette* of 4th July 1916' in *Jellicoe Papers I*, p.293. See also 'Diaries of Stephen King-Hall' (*op. cit.*) pp.451-5.
[118] *Lion*, 'Record of Events'.
[119] *Princess Royal*, 'Record of Action'. *Tiger*, 'Gunnery Records'. *New Zealand*, 'Record of Ranges'.
[120] Campbell, *Analysis*, pp.89-94 attributes these hits without explanation to *Tiger*. Since her fire was by then

Royal was not even under fire, after 4.17 the shooting of the British battlecruisers did nothing to take the pressure off *Queen Mary*, while *Lion* received two hits from *Lützow* at 4.24.[121] *Queen Mary* had probably already been hit twice by *Seydlitz* before, at 4.21, the right gun of Q turret was put out of action. von Hase spotted *Derfflinger's* first straddle at 4.22.40, when his rate was -330 yds/min. After spotting the fall of the next three salvoes, he ordered rapid fire, which produced six salvoes with an average interval of only 22 seconds; at 4.26, after two further hits, *Queen Mary* was sunk by explosions in her fore and midships magazines.[122]

At 4.25, *Princess Royal's* ranges were beginning to converge on *Derfflinger's*. There is then an unexplained gap of almost six minutes in *Princess Royal's* salvo record. Since Beatty originated a wireless order at 4.25 ordering her to 'Keep clear of smoke', it appears that, once again, she had failed to keep out of the flagship's smoke. *Princess Royal* may have responded to the signal by turning to SE for a time.[123] She now became the target for *Derfflinger* and Campbell assumes that the British ship received three further hits; however, they were not well documented and their effects were slight, so only one (on the second funnel) has been included here in the German total.[124]

Only a minute after the destruction of *Queen Mary*, Hipper turned away to SE,[125] so that the range began to increase. *Tiger* narrowly avoided the wreck by hauling out to port; she changed target to *Seydlitz* but herself became the target for *Seydlitz* as well as *Moltke* and received three further hits. Her ranges fell to improbably low values but it does appear that, once again, she got closest to the enemy.[126] After losing sight of *von der Tann*, at 4.17 *New Zealand* had shifted her fire to *Moltke*, but her ranges did not begin to decrease decisively until after she had passed the wreck of *Queen Mary* on its starboard side. Her ranges did not fall as far as those of her consorts, while there are several gaps in her salvo record;[127] thus it appears that she remained somewhere on their starboard quarter and

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erratic (Note XXVI-16), they might have been lucky hits: except that, when her fire strayed, it was towards the head of the German line (*Tiger's* Gunnery Officer, pp.424-5).

[121] Beatty's Personal Narrative. Campbell, *Analysis*, pp.67-9.

[122] Williams, 'Loss of *Queen Mary*' (*op. cit.*) pp.122-5 and 132. Campbell, *Analysis*, pp.62-4. Note XXVI-15 concludes that *Seydlitz* made three hits up to 4.21 and *Derfflinger* two at 4.26. von Hase, p.160; for rapid fire, see also pp.148-9.

[123] *Princess Royal*, 'Record of Action'. British 'Record of Messages'. 'Officers of *Princess Royal*' p.19.

[124] von Hase, pp.162-4. Campbell, *Analysis*, pp.69-71.

[125] German 'Summary of Messages'.

[126] Williams, 'Loss of *Queen Mary*', p.129. *Tiger*, 'Gunnery Record'. Campbell, *Analysis*, pp.47-8 and 73-5.

[127] *New Zealand*, 'Record of Ranges'.

that, as would be expected, their smoke interfered at times with her fire. As in the first phase, she made no hits on either of her targets.

For the second phase of the Run to the South, the 1SG must be allowed at least another 12 hits on the British battlecruisers: whereas, if the two hits on *von der Tann* are discounted, the British battlecruiser tally was only three.[128] These three were all made at the start, when ranges were long, and hint at what might have been accomplished if the approach had been less precipitate. Unfortunately, these early successes were not sustained, though for different reasons. *Lion's* ranges were again too few, while her transmitting station ignored their clear downward trend and the rate in use was insufficiently closing until after her turn from SE to SSE. *Princess Royal's* ranges were converging on *Derfflinger's* at 4.25, but, at this critical moment, *Princess Royal* once more got into *Lion's* smoke. *Tiger's* previous damage rendered her target selection uncertain and her fire ragged and ineffective. *New Zealand's* own gunnery record shows that she was slow in reducing the range and suggests that she suffered from smoke interference once she did so. Thus neither of the rear ships supported its consorts effectively.

Beatty's tactics again failed to exploit the advantage of his heavier guns. *Lion's* rapid approach without signals left Admiral Brock little time to decide for himself how best to prevent any risk of collision, allow the flagship to regain the head of the line and avoid smoke interference. All these things could not be accomplished before the Germans were able to reopen fire within their effective range and with the visibility in their favour. Beatty's ships once more found themselves forming their line under fire, while at least two of them were soon to be hampered by smoke; the 1SG, despite the efforts of the 5BS at very long range, soon regained gunnery superiority. Most importantly, because Beatty commenced his approach before reforming his line, *Lion* was partly obscured so that *Derfflinger* selected the third ship as her target. And, because the fire of the other British battlecruisers was too ineffective to punish the German mistake, *Derfflinger* and *Seydlitz* were able to concentrate undisturbed on *Queen Mary*, with terrible consequences for her and her crew.

While Beatty's conduct of both approaches disadvantaged his ships even before fire was opened, the 1SG were successful in exploiting to the full the advantages handed to them. Their most rapid rate of fire was so impressive that, after Jutland, the Royal

[128] *von der Tann* made one hit on *Barham*: while the 5BS scored at least 5, probably 7, on *von der Tann* and *Moltke*.

Navy assumed its opponents had fired multiple salvoes in quick succession, even while still finding the target. This led to adoption, in the new 1916 Spotting Rules, of the ladder system, under which pairs of salvoes were fired in quick succession, separated by a fixed distance, both being spotted before firing the next pair.[129] In fact, no evidence has been found that the Germans used ladders at Jutland. While finding their targets, they and the British mostly fired at similar rates, with, typically, around 50 seconds between salvoes (XXVI-16). However, the distinguishing feature of the German firing was their use of rapid unspotted fire, but only when the target had already been consistently straddled. *Lützow* and *von der Tann* both fired in this way[130] but the system is described most clearly by von Hase of *Derfflinger*.

> ...now I had found the target....the transmitting station was to give the order "Salvoes-fire!" to the heavy guns once every 20 seconds....While the firing was going on any observation was out of the question....Naturally such furious rapid fire could only be maintained for a limited time....It was not long before our salvoes fell over or short....Each salvo was then directed afresh and this continued until the target was again straddled. And then the devil's concert began again on the order "Good, Rapid".[131]

The British gunnery records for the Run to the South contain no sequence of repeated straddles followed by a rapid burst, all at a steady rate, like that which sank *Queen Mary*.[132] In marked contrast, when *New Zealand* opened fire at *3.51*, she broke immediately into rapid salvoes fired mostly at 30 second intervals;[133] this wild fusillade (undoubtedly another case of taking 'the rapidity ideas...to excess') must have made consistent spotting impossible, and she made not a single hit.

Yet, later in the battle, British battlecruisers and battleships also demonstrated that the key to effective shooting was to follow up consistent straddles with bursts of rapid salvoes. After straddling, *Barham* 'fired four more salvoes rapid and straddled again'.[134] At 5.44 and 6.19, *Lion* ordered rapid fire and made hits on *Lützow* with salvoes fired at half-minute intervals.[135] Just before *Invincible* was sunk, when she had been hitting *Lützow* repeatedly, Admiral Hood was urging her Control Officer to 'keep at it as quickly as you

[129] Roberts, *Battlecruisers*, p.94. *FDSF III*, p.196.
[130] *German Official Account*, p.61. Campbell, *Analysis*, pp.40,43,61 and 364. Note XXVI-16.
[131] von Hase, pp.148-9. When ranges were less than 13,000 m. two salvoes from the secondary armament were fired after each heavy salvo.
[132] *ibid.* p.160, reproduced in XXVI-16.
[133] *New Zealand*, 'Record of Ranges'.
[134] Blackett, 'Naval Diary', 31 May 1916.
[135] *Lion*, 'Record of Events'. Campbell, *Analysis*, pp.135, 183 and 264. *Princess Royal's* 'Record of Action' does not support Campbell's tentative attribution to her of the hit on *Lützow* at 5.45. *Lützow* was hit twice *c.*6.19. *Lion* also fired 14 rapid salvoes, though with large spotting corrections until the 9th, from 8.22 until 8.28 (one hit on *Derfflinger* at 8.28).

can, every shot is telling'.[136] And *Iron Duke* (Flag Captain Frederic Dreyer) gave what Campbell describes as 'a fine display of speedy and accurate firing' against *König*.[137] The target was sighted at 6.26 but fire was not opened until 6.30.25, time enough for the Dreyer Table Mark IV to establish the enemy course as 'slightly converging' and the range as 11,000 yards. The spread of the range plot of 500 yards determined the size of the opening bracket. After four salvoes (at intervals of 35, 40 and 50 seconds), the third and fourth were spotted as hits, after which rapid fire was ordered, the next three salvo intervals being 30, 25 and 23 seconds. The salvo rate then slowed as *König* turned away into the mist:[138] but not before she had received at least seven direct hits.[139]

After the battle, a Grand Fleet Gunnery & Torpedo Order acknowledged the usefulness of the Dreyer Tables in difficult conditions.

> Notwithstanding the bad light and mist, some ships obtained good ranges which proved of great value, and it was again proved that every conceivable method should be employed to gain data with which to feed the fire control table. The difficulties introduced by enemy and our own alterations of course, speed, etc. make this imperative. The deflection must also be watched closely.[140]

Supporters of Pollen, like Herbert Richmond, took the view that Dreyer, as Jellicoe's flag captain, could and did stifle any criticisms from the Fleet of 'his' tables.[141] However, Beatty and Chatfield bore no responsibility for the Navy's fire control equipment; if they believed that the Dreyer Tables had in any way failed them, they would surely have seized on the excuse. In fact, the Battle Cruiser Fleet's own committee on the lessons learned concluded:

> The action...appears to show that more value was obtained from rangefinders by some ships than by others, and that at such times as the enemy was on a steady course undoubted assistance was received from the plot.
>
> It is again strongly emphasised that the enemy system of continuously altering course

[136] Commander H E Dannreuther, Gunnery Officer of *Invincible*, to Captain F W Kennedy, *Indomitable*, 2 June 1916 in ADM 137/302. As explained in Appendix XXIX, it appears that, of the 3rd Battle Squadron, *Invincible* alone was responsible for the eight damaging hits then made on *Lützow*).
[137] Campbell, *Analysis*, p.156.
[138] Dreyer, 'Brief Account': Commander (G) Blake, 'Notes made in the...Gun Control Tower': Commander Calvert, 'Notes made ... in "B" Turret" and Lieut. Shelley, 'Notes...on...Transmitting Station' in ADM 137/302.
[139] Campbell, *Analysis*, pp.156 and 187-193 attributes one of the direct hits to *Monarch* but that ship's 'Notes taken during the Action off Jutland...' (in 'Jutland Additional Reports', ADM 137/1643) suggest that she was probably firing at another *König*-class ship, perhaps *Markgraf*, which was also hit at this time. *König* was also hit by a ricochet.
[140] *GFG&TO*, 167. 'Remarks on the action off Jutland on 31 May 1916', 17 July 1916.
[141] *IDNS* (*op. cit.*) p.308.

> defeats any system of fire control based on rate-finding, for the reason that by the time the plot has established a rate it is no longer applicable.[142]

Thus the new Spotting Rules included specific provisions for the correction of range and rate when the enemy altered course.[143]

THE DREYER TABLE COMMITTEE

> The development of [the] spotting rules and afterwards the solution of the problem of concentration of fire, constituted the main work of the Fleet during the latter half of 1916, and in 1917 and 1918. The progress has been enormous.[144]

Action ranges from 15,000 to 18,000 yards were assumed,[145] but practices were conducted at up to 24,000 yards, while the new technique of 'throw-off' firing made them much more realistic.[146] Although 13.5-inch as well as 15-inch ships had been provided with 15-foot range-finders,[147] it was accepted that 'small rangefinder spreads were the exception'.[148] Nonetheless, the *Grand Fleet Gunnery and Torpedo Orders* warned against:

> ...the neglect of the range plot which on numerous occasions during throw-off firings provided information which could have been utilised to great advantage.
> ...many [plots] were excellent and afforded throughout a good indication of the rate and true range; on the other hand some present large and varying differences between hitting gun range and mean plotted range.[149]

The range plot also had a new importance as a means of recording the ranges in use by consorts in concentration firing.[150]

In contrast, it is doubtful whether the original bearing plot was of more than marginal utility. An American naval officer with the Grand Fleet found that: 'The bearing plot instrument is not generally taken seriously':[151] while the post-War *Technical History and*

[142] Chatfield, *Navy and Defence*, p.153. BCF Gunnery Committee, 'Gunnery lessons learned from Action of 31st May', 22 June and 'Additional remarks', 24 June 1916 in *Beatty Papers I*, particularly pp.347-50 and 363. Several passages from these reports were quoted verbatim in *GFG&TO*, 167.
[143] Admiralty, Gunnery Branch, *Spotting Rules 1916*, November 1916 in Ja011, AL. For the development of these rules, see 'Battle Cruiser Force War Records: Volume VI, Miscellaneous', ADM 137/2134 and 'Committees formed to consider experience at Jutland, Part II', ADM 137/2028.
[144] Admiralty, Technical History Section, *The Technical History and Index. A Serial History of Technical Problems dealt with by Admiralty Departments*, Part 23 'Fire Control in H.M. Ships', December 1919, pp.21-2, AL.
[145] 'Notes on tactical exercises...24 February 1917' and 'Grand Fleet Battle Instructions', 1 January 1918 in *Beatty Papers I*, pp.403 and 457.
[146] Admiralty, Naval Staff, Gunnery and Torpedo Division, *Progress in Naval Gunnery 1914 to 1918*, July 1919, pp.50-1, ADM 186/238.
[147] Enclosure with Admiralty to C.-in-C., 10 October 1916 in ADM 137/2027. *PNG 1914-18* (*op. cit.*) states that, in August 1917, there were 106 15-foot rangefinders in the Fleet.
[148] *GFG&TO*, 312. 'Rangefinder Errors', 29 December 1917.
[149] *GFG&TO*, 105. 'Full Calibre firings with Main Armament...during second quarter, 1918', 10 September 1918, paras.31-2.
[150] *GFG&TO*, 91. 'Full Calibre firings...in first quarter of 1918', 29 June 1918, paras.13 and 31.
[151] Quoted in William Schleihauf, 'The Dumaresq and the Dreyer' in *Warship International*, No. 3, 2000

Index admitted that: 'Bearing plots have not been an unqualified success...'.[152] However, in 1918 the Grand Fleet committee was already at work on the Gyro Director Training (GDT) gear, which plotted bearings transmitted from the Director in steps of 4 minutes. It also introduced an important new principle, that of the 'straight-line' plot, in which a straight line up the middle of a narrow strip of moving paper always represented the target compass bearing predicted by the bearing clock. Each observed compass bearing was plotted as its *difference* from the current predicted value; thus, as well as showing the deviation of observed and predicted values, the slope of the mean line through the plot of observed bearings also indicated the error in the clock rate.[153] This enhanced version of Dreyer rate plotting would soon be taken up as the basis for plotting in a new generation of fire control tables.

In September 1918, Beatty set up the Grand Fleet Dreyer Table Committee. Their First and Second Interim Reports, which concerned the Mark V table then being built for HMS *Hood*, were critical of the excessive number of fittings obscuring the plot, but, *pace* Sumida,[154] concluded only of this plot that: 'A considerable alteration in design is therefore necessary'. However, they also expressed concern about:

> *The drive of the Frictional Clock Disc.* - Many complaints have been received that this disc is not sufficiently strong for the work now imposed on it. It is considered that the power of the motor should be greater, and that the diameter of the shaft carrying the roller should be increased.[155]

In fact, the first clear indication of this problem can be found almost a year earlier:

> **Overloading the Dreyer Table.** Attention is drawn to the necessity of circumspection in adding fittings to the Dreyer Table; if driven by the rate disc it is essential that they should be fitted with great care and thoroughly tested to ensure against overloading and slipping, as occurred in one ship.[156]

Even so, the standard tables do not appear to have suffered from excessive slippage, even when the rate changed rapidly while under helm.

> In certain firings [during the first quarter of 1918] the range and deflection were maintained very successfully during turns of twelve points and upwards.[157]

(advanced copy gratefully acknowledged).

[152] *Technical History*, 1919 (*op. cit.*) p.30.

[153] *Technical History*, 1919, pp.28-9. Admiralty, Gunnery Branch, *Handbook on Gyro Director Training Gear (GDT) 1927*, ADM 186/279.

[154] *IDNS*, pp.312-3.

[155] 'First and Second Interim Reports' in Admiralty, Gunnery Branch, *Reports of the Grand Fleet Dreyer Table Committee 1918-1919*, September 1919, pp.4-5, ADM 186/241.

[156] *GFG&TO*. 304. 'Full Calibre Firings...in third quarter, 1917', para.III/23.

[157] *GFG&TO*, 91 (*op. cit.*) para.41.

In October, the Committee was instructed to consider two much broader questions. The first, which was addressed in their Third Interim Report of 29 January 1919,[158] concerned 'standardising the alterations which are being made by various ships to their Dreyer Tables'. The request was repeated for the strengthening of the friction drive, in the Mark IV as well as Mark V Tables; clearly, this was necessary to accommodate new fittings on the range plot. Notwithstanding the inadequacies of the old bearing plot, the report emphasised that:

> The measurement of rate of change of bearing is considered of great importance owing to the accuracy with which bearings can be observed, even when the visibility is poor.... ...bearing observations can be obtained *continuously* and *accurately*.

It accepted that 'The Gyro Director Training Gear...will standardise the arrangements for dealing with rate of change of bearing': though it also acknowledged that 'the present system of correction' of the gyro-compass, with which 'oscillations take place when course is altered',[159] must be improved.[160]

The Committee's conclusions concerning the time-and-range plot marked a radical change in assumptions.

> *Experience has shown, and it must be accepted, that it will very seldom, if ever, be possible to obtain the rate of change of range from rangefinders*....The frequent alteration of course at high speed which are now the accepted conditions of action will preclude the rate...being obtained with sufficient rapidity from a time and range plot.
>
> The setting of the enemy bar must, therefore, be obtained from the rate of change of bearing and the inclination found by inclinometer, observation or outside reports (*e.g.* aeroplane)....[161]
>
> ....
>
> ...It is considered that the primary object of plotting the rangefinder observations is to enable them to be "meaned" by inspection for the purpose of checking gun range...and to allow the value of the rangefinder readings to be assessed....[162]

They repeated these axioms in their Final Report, submitted on 1 February 1919, which addressed the second question of 'the Fleet's requirements for the future development of Fire Control Tables generally'. However, although true-course plotting was considered, it was decisively rejected as an alternative to separate plots of ranges, bearings and, now, inclination.

[158] 'Third Interim Report', *Dreyer Table Committee* (*op. cit.*) pp.5-13. For the date, see 'Monthly Record of Principal Questions dealt with by Director of Naval Ordnance, Vol.3, January to June 1919, p.1093, AL.
[159] The imperfections of the gyro-compass itself explain why 'the arrangements for applying corrections for changes in course...were apparently highly unsatisfactory': *IDNS*, p.313.
[160] For the introduction of the gyro-compass with mercury ballistic from 1919, see A E Fanning, *Steady as She Goes* (London, 1986) pp.218-228.
[161] This cross-cut of inclination and speed-across gave the range-rate as well as the enemy speed.
[162] 'Third Interim Report' (*op. cit.*) p.6.

> When observations and information of the enemy's movements and fall of shot becomes so good and rapid as to enable a correct track to be plotted, these results can be set direct on the clock, and the necessity of plotting for gun control purposes vanishes.

While the Committee had no interest in reviving the Argo plotter, they proposed that the new table should be a 'combination of all the good points of the Dreyer table, Ford clock,[163] and Argo clock'; in particular, they accepted that, in the Dreyer Tables:

> The drive of the automatic Dumaresq...is not the best available type of variable speed gear.

They also recommended that the straight-line system should be used for both range and bearing plots; and that, to deal with the increased amount of range information, two time-and-range plots should be placed side by side.[164]

THE ADMIRALTY FIRE CONTROL TABLE MARK I

In most respects, the first of the new generation of fire control tables, the AFCTs Mark I fitted in *Nelson* and *Rodney*, followed the recommendations of the Grand Fleet Committee. The final design had no less than three time-and-range plots and two time-and bearing plots, all on the straight-line principle (Plate 54). Thus there was no 'adoption of..true-course plotters...after the war'.[165] Nonetheless, the clock was based on the Argo-type variable-speed drive, although the linkages which generated the speeds along and across were more like those in the Ford clock.[166] However, the Committee's enthusiasm for the direct measurement of inclination, as a complete replacement for range-rate plotting, proved premature. The difficulties of designing and using inclinometers became increasingly apparent, and a fully satisfactory instrument did not enter service until 1927.[167] By 1923, it had been accepted that the inclinometer was yet

[163] For the American Ford Instrument Company, see *IDNS*, p.314.

[164] 'Final Report of the Committee. Future Development of Fire Control Tables', *Dreyer Table Committee*, pp.14-19. For its date, see 'MR/DNO' Jan-June 1919 (*op. cit.*) p.1114.

[165] *IDNS*, p.331.

[166] Admiralty, Gunnery Branch, *Handbook for Admiralty Fire Control Table Mark I (H.M. Ships "NELSON" and "RODNEY")*, September 1927, ADM 186/273-4. Hannibal C. Ford, *Range and Bearing Keeper*, US Patent 1,450,585 filed 19 June 1918. Ford's Range Keeper (US Patent 1,370,204, filed 4 December 1917) used the same principles but only for generating range-rate.

[167] For early optimism about inclinometers, see *GFG&TO*, 105 (*op. cit.*) para. 26: *GFG&TO*, 123. 'Present position as regards Inclination and Methods of using Inclinometers', 4 November 1918: *PNG 1914-18*, pp.32 and 42: and *Technical History*, 1919, p.30.

For later developments and problems, see Admiralty, Gunnery Branch, *Progress in Gunnery Matériel 1920*, pp.12-15, ADM 186/244. Admiralty, Gunnery Branch, *Progress in Guinnery Material 1922 and 1923* (printed November 1923) pp.14-25, ADM 186/259. Admiralty, Gunnery Branch, *Progress in Naval Gunnery 1923* (p.12), *1924* (pp.3 and 12), *1926* (p.13) and *1927* (p.10), ADM 186/261, /263, /271 and /289. The Barr & Stroud SF7, supplied in 1927, was accurate to 2° if the inclination was less than 70° or greater than 110°.

one more source of less than precise data. On top of the new clock, the larger dial indicated enemy course (as inclination) and speed. Above this, two 'suggestion wires', at right angles, were positioned according to the slopes of the straight-line plots of observed ranges and bearings (Plate 55). The point of intersection of the wires provided an indication of how to alter enemy speed and course in order to tune the clock's range and bearing rates into closer correspondence with observations. However, an alternative suggestion for enemy course was given by an inclination pointer projected onto the enemy dial.[168] Thus the suggestion wires were a physical realisation of the cross-cut of range-rate and speed-across so long advocated by Dreyer: while the inclination projector extended the principle by providing for the alternative cross-cut of inclination and speed-across advocated by the Grand Fleet committee.

In recommending their Final Report to the Admiralty, Beatty had proposed that the design be undertaken by a committee of experts which should include both Isherwood and Elphinstone.[169] As originally formed, the 'Fire Control Tables Development Committee' had only Service members,[170] but Isherwood (assisted by H F Landstad, a senior draughtsman from Argo) joined them in 1920 and 1921 to assist with mechanical design.[171] The final design, which was not completed until 1925, was later described as 'a co-operative effort by the F.C. Tables committee, designers on Messrs. Elliott Bros. staff and the L.P. and F.C. section of the D.T.M. Department';[172] unfortunately, no clear indications have been found of when Elliotts began to contribute to the design process nor, therefore, of whether Isherwood and Elphinstone (now Sir Keith) had worked for a time in collaboration.

The committee's reports were submitted just as Frederic Dreyer left the Admiralty in February 1919 to serve as Chief of Staff during Jellicoe's Empire Mission. However, he returned in April 1920 to take up his previous duties (under the title of

[168] *PGM 1922-3* (compiled in the 'early months' of 1923) pp.9-12. *Handbook for AFCT Mark I* (*op. cit.*).
[169] Beatty to the Secretary of the Admiralty in *Dreyer Table Committee*, pp.18-9.
[170] 'List of Admiralty Committees and Committees in which the Admiralty is interested', September 1919, ADM 1/8568/259.
[171] Hugh Clausen, 'Invention and the Navy - the progress from Ideas to Ironmongery', paper to the Institute of Patentees and Inventors, 30 January 1970 published in *The Inventor*, Vol. 10, No. 1, March 1970, CLSN 3/7. Examination of Commander Isherwood in RCAI Minutes of Proceedings, T.173/547 Part 10, pp.5,100 and 103,: and Pollen to the RCAI Secretary, 28 July 1926, pp.2-3 in T.173/90.
[172] Capt. E T Wickam and H F Simes, 'Branch 5 of the Electrical Enginnering Department of the Admiralty. Some Account of its History', September 1953, p.4 in CLSN 5/3, CC. The 'Low Power and Fire Control Section' of the department of the Director of Torpedoes and Mines became 'Branch 5' of the E.E. Department after it was transferred in 1939.

Director of the Gunnery Division) for two more years.[173] Thus he had plenty of opportunity to influence the Development Committee's conclusions and the start of detailed design.[174] Yet, a year after his return, Dreyer had only one concern about the way the development was proceeding.

> ...D. of G.D. was for a long time very anxious as regards the effect of the very complex proposals for the new Fire Control Table, but eventually arrived at the conviction that they were necessary in order to face the problems with which we are confronted....[175]

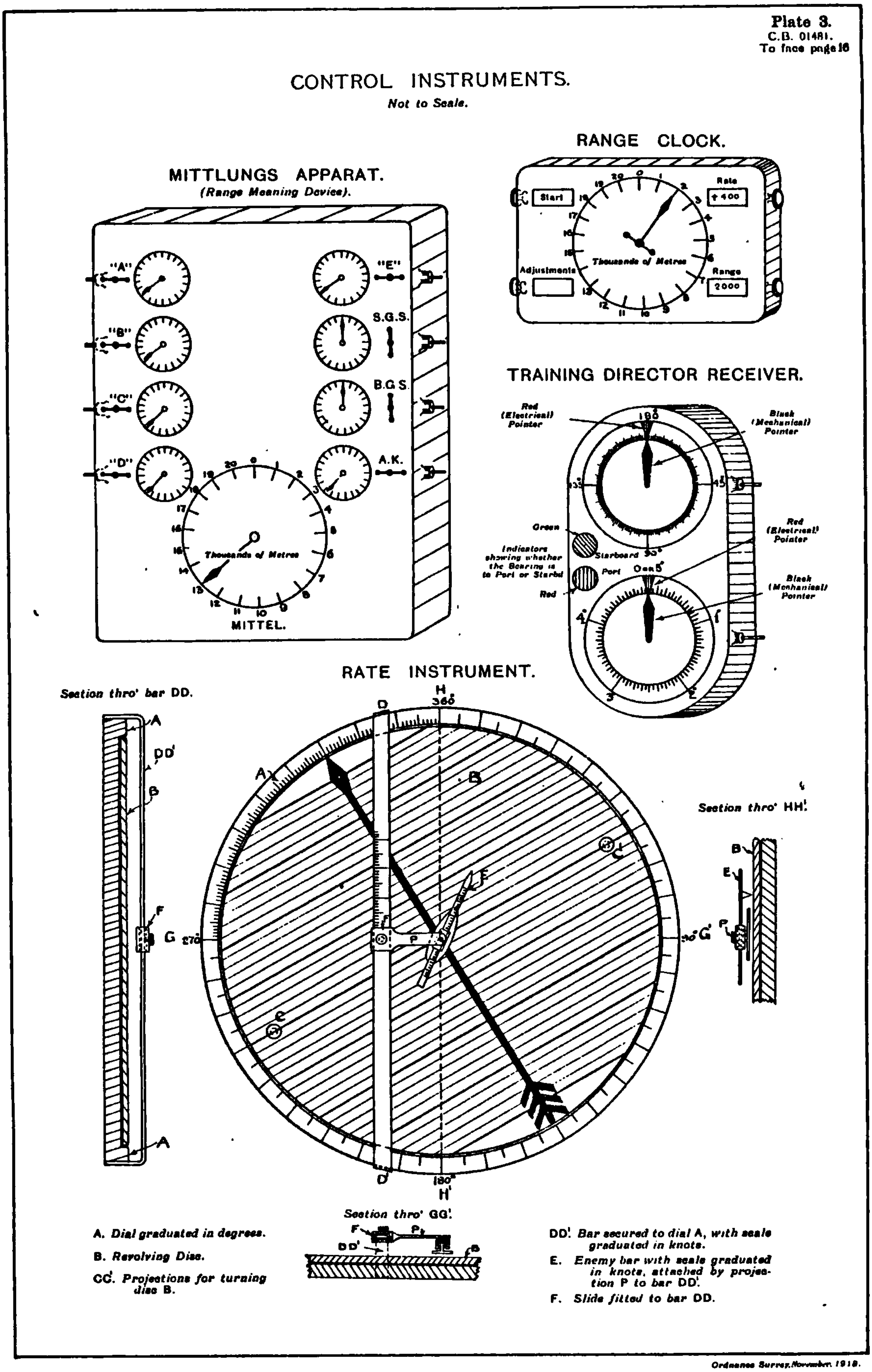
After the first trials of the prototype AFCT Mark I at the end of 1925, Dreyer, now a Rear-Admiral and back at the Admiralty as ACNS, reaffirmed that:

> I am quite sure that the Policy pursued and the money expended in connection with these experimental Tables are fully justified.[176]

Sumida suggests that, after Dreyer returned as DofGD, 'the design process was well under way, but political circumstances [the presence of Beatty as First Sea Lord] were also such as to limit severely his powers of interference' and that, as ACNS, he 'had good reason to be circumspect in his remarks' because of the recent exposure by the Royal Commission on Awards to Inventors of 'the plagiarization [*sic*] of the Argo Clock that had occurred in 1911'.[177] These interpretations might be justified if the Argo fire control system had been the basis for the AFCT Mark I. In reality, as a complete system, there is some justification for Dreyer's claim that the AFCT 'was in fact only a rearrangement of my "Dreyer Table" ',[178] despite the clear Argo influence in the variable speed drives of the clock. Thus Dreyer had no reason to interfere with the development of the Mark I, or to dissimulate his enthusiasm over the outcome; not a hint has been found that he did not give the new table his full support.

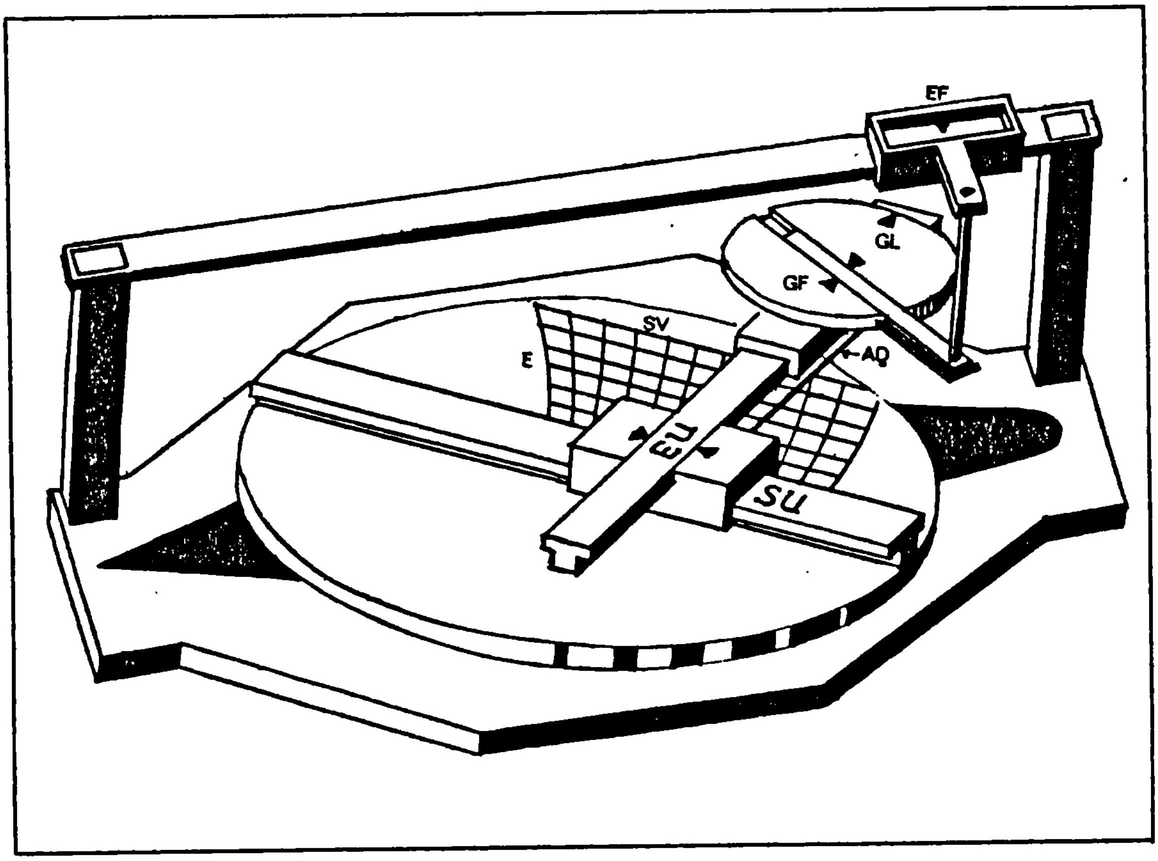
[173] Frederic Dreyer, *The Sea Heritage* (London, 1955) pp.236, 239, 261 and 276.
[174] No details had been finalised in March 1920: 'Final Report' p. 31 with President's Minute of 9 March 1920 in 'Fire Control Requirements Committee... Report, Admiralty remarks &c.' 1919-1921, p.31, ADM 116/2068.
[175] Dof GD's minute, 15 April 1921 in 'PQ/DNO', 1921, pp.2275-6.
[176] ACNS's minute, 4 January 1926 in 'Fire Contol Table. New Design' in 'MR/DNO', Vol. IX, July 1923 -June 1926, pp.3180-8.
[177] *IDNS*, pp.315-6.
[178] Dreyer, *Sea Heritage* (*op. cit.*) p.59.

Plates for Chapter 6



52. German Fire Control Instruments.

Naval Staff, Intelligence Department, *German Gunnery Information Derived from the Interrogation of Prisoners of War*, October 1918, Plate 3, AL.

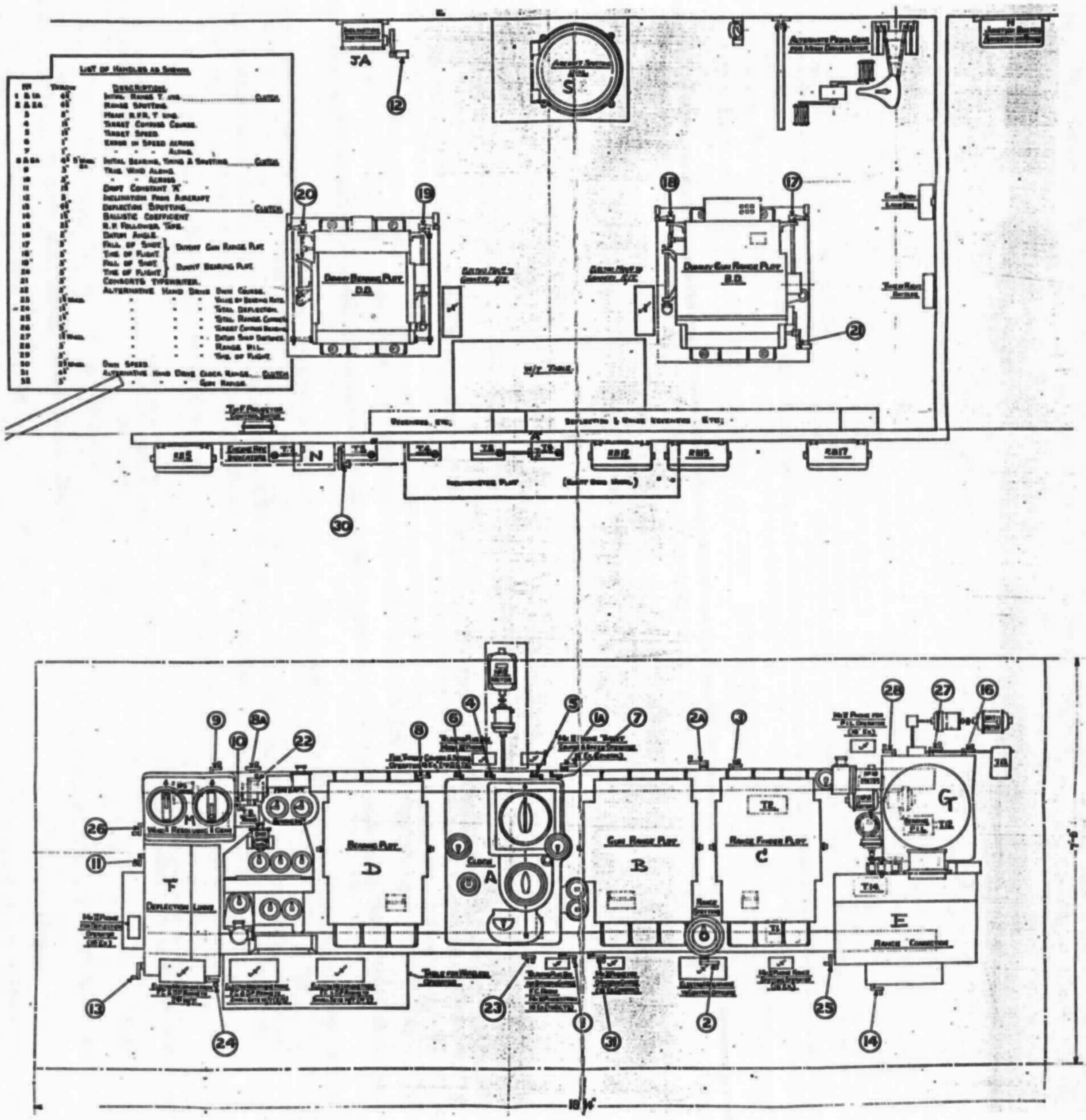


German First World War Fire Control apparatus, Z 31 EU/SV–Anzeiger (range rate/deflection reporter), a refined Dumaresq. EU=range rate; SU=bearing rate; E=range; SV=deflection; GF=enemy speed; GL=enemy position; EF=own speed; AD=indicator.

53. Z 31 EU/SV Anzeiger.

The instrument indicated range-rate (EU) and gun-deflection (SV) corrected for range (E).

Peter Padfield, *Guns at Sea* (London: Hugh Evelyn, 1974) pp. 228 and 250.



54. Admiralty Fire Control Table Mark I

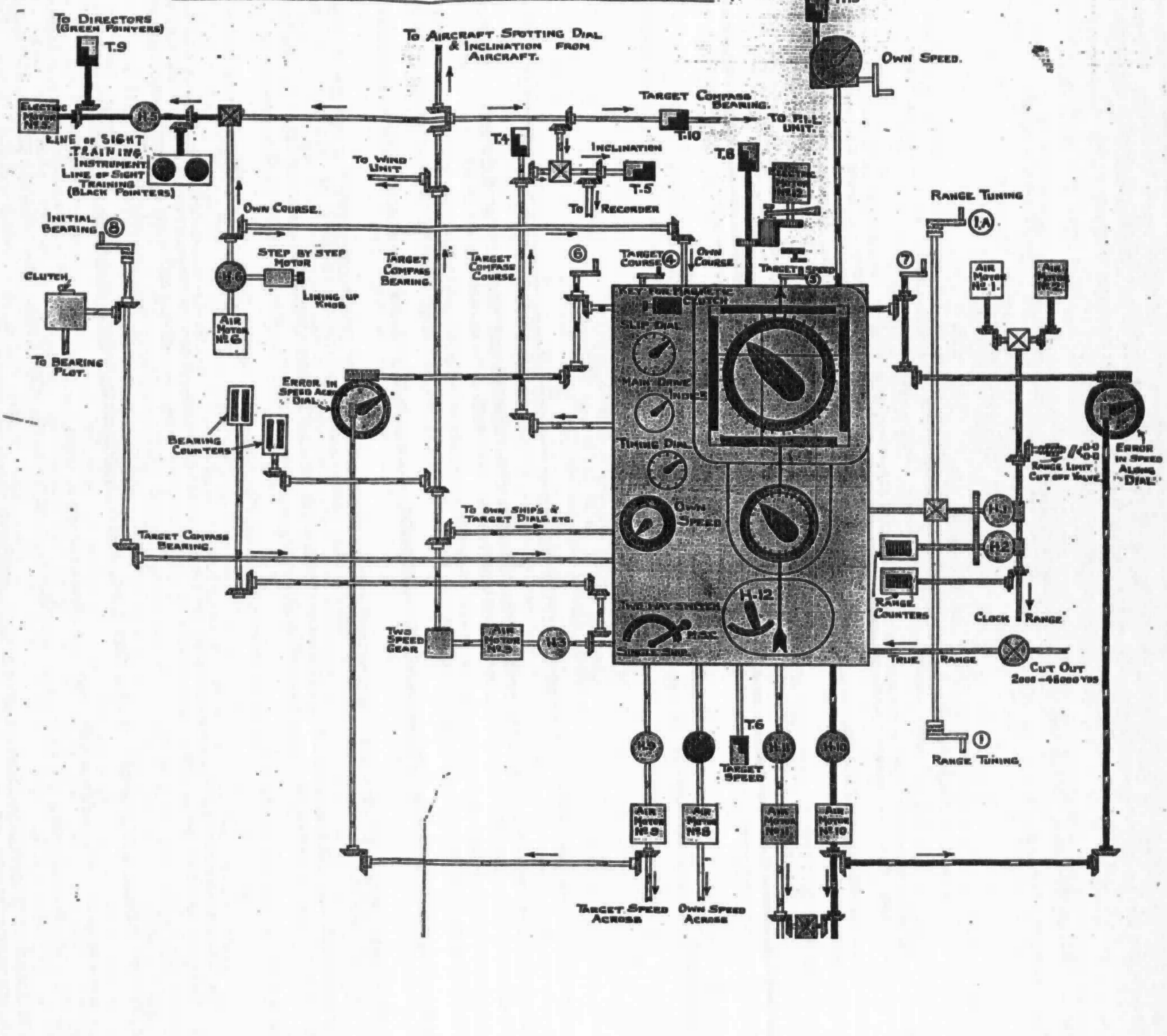
To avoid congestion around the main table, the Dummy Plots (BD and DD) plotted all fall-of-shot observations and consorts' ranges and bearings; all these data were duplicated on the Gun Range and Bearing Plots (B and D).

The Range Finder Plot C recorded the ranges received from all the rangefinders. A pencil was tuned to the mean rangefinder range. The Gun Range Plot D plotted this mean rangefinder range, the gun ranges of own ship and of consorts, corrected for position-in-line.

On the Bearing Plot D, the Director Bearing could be compared with the target bearing predicted by the clock.

Admiralty, Gunnery Branch, ***Handbook for Admiralty Fire Control Table Mark I...Diagrams***, Plate 1 (detail), ADM 186/274.

FIGURE 4. LEAD OF SHAFTING INTO CLOCK.



55. AFCT Mark I: Top of Clock with Mechanical Connections

The two 'suggestion wires' intersect above the larger dial, which showed target course and speed. The wires followed any changes in the speeds along and across but were further displaced by the values set on the two 'error' dials. Smaller dials indicated own course and speed.

The clock drove the many other mechanisms in the table by means of the electric and air motors, each with a controlling hunter (H.1 - H.11).

Admiralty, Gunnery Branch, ***Handbook for Admiralty Fire Control Table Mark I...Diagrams***, Plate 4, ADM 186/274.

7

An Exceptional Case

It is now possible to address directly the three questions posed in the Introduction. Firstly, what technical influences shaped the designs of the Pollen and Dreyer gear and, in particular, were features of the Dreyer Tables plagiarised from Argo? Secondly, were the Admiralty's choices of technology and supplier justified? And, finally, what were the consequences of the choice of the Dreyer system; specifically, did it contribute to the defeat of Beatty's battlecruisers at Jutland: and could ships equipped by Argo have coped better with the conditions?

Influences

In October 1925, the Royal Commission on Awards to Inventors granted Pollen the considerable sum of £30,000 for his work on fire control. However, their judgement was by no means all in his favour. The Commission again rejected his claims for rate plotting, and came close to accusing him of misrepresentation.

> ....After 1908 the Admiralty developed a system with another method of plotting, which Mr. Pollen then regarded we think rightly as something different from the method or system which he himself advocated. We do not think the view he now presents is consistent with his earlier view...

The award itself was only for the Argo clock, while the judgement was at pains to 'acquit all concerned of any intention or desire to copy'.

> ...we are satisfied that Mr. Pollen and the Argo Co. Ltd. were the first to produce a mechanical integrator...namely the Argo Clock, and that the clock mechanism of the Dreyer Tables Mark IV and V works substantially on the same principles though there are differences of mechanical detail.[1]

[1] 'Royal Commission on Awards to Inventors. Claims of Argo Company and A H Pollen, Rear Admiral Dreyer and Major Dumaresq. Recommendation', 30 October 1925 in DRYR 2/2, CC. Reproduced in

It is clear from the hearings that the Commissioners made their award only for what was referred to as the 'two-rate clock'.

> THE CHAIRMAN: ...it is pretty plain that there are two features...in the Dreyer apparatus Mark IV and V which are not to be found anywhere else; one of those features is the clock plot, and the other...is the mechanism for moving the fore and aft bar to accord with the movements of the ship....I do not think there is any dispute about it that they are novel features and the entire credit...rests with Admiral Dreyer.[2]

However, the judgement itself made no distinction between the two most important features of the later Dreyer Tables: that they automatically integrated both range and bearing rates: and that they automatically adjusted the Dumaresq's fore-and-aft bar for changes in course. Read alone, the recommendation seems to imply that both features had been anticipated by Argo: while it also fails to give any indication of how, when and to what extent the Argo designs had exerted their influence. Nor does the judgement discuss a question which might have significantly influenced the size of Pollen's award: that is, the debt which his system owed to his long association with the Royal Navy.

From the very beginning, Pollen's proposals contained features already anticipated by service developments. Two-observer rangefinders had been tried unsuccessfully afloat in *Arethusa*, and were used for target course plotting in one form of the Watkin Position Finders in service with the coastal artillery.[3] Thus Arthur Pollen's first proposal of 1901 combined two well-known ideas with the novel suggestion of plotting own as well as target course. He also mentioned, vaguely, the possibility of gyroscopic correction for yaw; this idea was new but, despite Pollen's later claims, there is no contemporary evidence that it was seriously considered again until the *Jupiter* trials, or omitted due to lack of funds from the Admiralty.

In his two papers of 1904, especially 'Fire Control and Long Range Firing', Pollen developed his ideas for a complete fire control system. It now incorporated a straight-course plotting table, which moved the plotting paper mechanically but still relied on manual plotting of simultaneous ranges and bearings from the two-observer rangefinder. A new element was a clock; in July 1904, it was apparently only for ranges, an idea partly anticipated by Percy Scott's proposal of late 1903 for an integrating range clock. However, by December, it had become a 'change of range and bearing machine'. Pollen's early patents and tactical machines suggest that it was conceived as working on

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Anthony Pollen, *The Great Gunnery Scandal* (London, 1980) pp.252-5.

[2] RCAI Minutes of Proceedings, T.173/547, Part 18, p.3; see also p.11 and Part 17, pp.89 and 111.

[3] Dreyer before RCAI, T.173/547 Part 16, pp.91-4.

the virtual course principle, although, it took another five years to turn the concept into a working mechanism, the Argo Clock Mark I.

After the *Jupiter* trials in early 1905, Pollen abandoned the two-observer rangefinder and, seizing the opportunity presented by the new Barr and Stroud 9-foot rangefinder, proposed a gyroscopic mounting which was stabilised for yaw and transmitted both yaw-free bearings and simultaneously-taken ranges. Ranges and bearings were to be plotted on a fully-automatic straight-course plotting table. He also proposed transmitting elevation and deflection directly from the (non-existent) clock to the gun sights, but this was a year later than the trials of the Vyvyan-Newitt sight in the Channel Fleet, when Pollen was being advised by its gunnery officers. While relying on another supplier for the rangefinder, the rangefinder mounting and plotter were entirely new, as the Admiralty acknowledged during the contract negotiations in 1905. Despite the technical obstacles, prototypes of a dual-gyro reference, servo-controlled mounting, transmission system and automatic plotter were completed for the *Ariadne* trial in early 1907 and performed well. Even so, the gyro reference and the plotter were redesigned completely for the *Natal* trials. Prior to these new trials, it was also decided to use standard Vickers follow-the-pointer sights rather than special Argo designs (which probably were never built). And, at last, the final essential component of the A.C. system, the range-and-bearing clock, was completed. This incorporated an early version of the Argo variable-speed drive (though it was not slipless); also, the discs were driven by a speed-regulated electric motor, so the clock mechanism was sufficiently powerful to drive range and deflection transmitters.

As first delivered to *Natal* in late 1909 and early 1910, the A.C. system was in no sense helm-free. The clock could only keep ranges and target bearings while own course was steady. The rangefinder mounting was yaw-free but its gyro reference had to be reset if the course was altered by more than one point. The plotter as first completed was automatic, but only on a steady course. In responding to Ogilvy's urgings to make the system helm-free, Argo's drastic attempt to modify the plotter for automatic operation proved disastrous. After the *Natal* trials, Argo developed the production version of the rangefinder mounting, though initially this was still only yaw-free. It only became helm-free when the Argo air-driven gyroscope was replaced by an Anschütz gyro-compass receiver. Likewise, the Mark IV plotter depended on a gyro compass input and on the Forbes speed log as well. Thus the final true-course Argo plotter, which by its very nature was helm-free, was not complete in itself but depended on technology acquired by the Royal Navy from other suppliers.

The Argo Clock Mark I had another surprisingly fundamental flaw: its range (the true or geometric range) and bearing could not be corrected from the plot without stopping the clock. The design of the Argo Clock Mark II of 1911 was founded on entirely different principles. It used a Dumaresq-type linkage to obtain a range-rate: and it set the range-rate on a variable-speed drive, which then integrated the rate to keep the range. This was no different in principle from the combination of Scott/Vickers clock and Dumaresq although, unlike the clockwork-driven Vickers clock, the new Argo clock, like its predecessor, was powered by an electric motor. Further, while the principles were the same, thanks to Isherwood's new slipless drive, the rate could be altered with minimal force, so the Argo version of the Dumaresq linkage could set the clock rate directly and automatically. This led to three more innovations. Argo proposed that, firstly, a second variable speed drive could act as a bearing clock and, secondly, that the bearing clock could keep the Dumaresq set for target bearing. Thirdly, after first suggesting that speed across could be converted into bearing rate by a simple linkage, they developed the Mark III design, in which a pair of variable speed drives in effect integrated speed-across divided by range to obtain the change in bearing applied to the Dumaresq dial. Once started, the clock could keep both range and bearing without operator intervention, provided that its own ship held a steady course i.e. it was automatic but not helm-free. Isherwood's design was a great advance, both functionally and mechanically, but, even so, the range-rate integrator and Dumaresq linkage had long been parts of the Service system, with which Pollen had been familiar since 1904.

Neither the Argo Clocks Mark III nor IV were automatic in a turn; a control lever was set to 'turning' after releasing the 'angle-of-courses' clamp, then the change in enemy bearing had to be set continually by hand. Also, the Mark III held the inclination constant in a turn, the same approximation first proposed by Dreyer in 1908 and embodied from late 1910 in the Mark VI Dumaresq. Automatic, helm-free operation - that is, range and bearing being kept automatically without operator intervention, whether own course ship was on a steady, yawing or changing course - was only achieved with the Argo Clock Mark V of 1913. This depended on a relay-motor connection between a gyro-compass receiver and the clock's Dumaresq, on the same principles used in the Dreyer Table Mark III of a year earlier. There is no direct evidence that Pollen learned of the details of either the Mark VI Dumaresq or the Dreyer table: though, given his acquaintance with Rear-Admiral Peirse[4] and many other sympathetic officers, it is not unlikely. However, even if Argo arrived at similar principles independently, they can have had no claim to priority of invention

To summarise: during its long gestation, there were many points at which the A.C. system was influenced by or depended on Service developments. The two-observer rangefinder had land-service antecedents, while the idea of automatic sights was not original. Had it not been for the new Barr and Stroud 9-foot rangefinder, Pollen would have had nothing to propose after the *Jupiter* trials except further development of the discredited two-observer system. The Argo rangefinder mounting, the true-course plotter and the Argo Clock Mark V all depended on the Anschütz gyro-compass for helm-free operation. Most importantly, after the abandonment of the Argo Clock Mark I, the starting point for the design of the later clocks was the long-familiar integrating range-clock set with range-rate from a Dumaresq-type linkage.

In 1925, the RCAI rejected Dreyer's own claim for a further award because of the £5,000 he had received in 1916. Nonetheless, of the Dreyer Table itself (specifically the Marks IV and V) they concluded:

> It has original features of considerable merit, the credit for which is due to Admiral Dreyer, even if in other respects it owes inspiration to other sources, or is the application of common knowledge.[5]

Thus, they had recognised that, while rate plotting owed nothing to Pollen, it was also not solely inspired by Dreyer. His 'rate calculators' of 1906 and 1907, mainly the latter, led only indirectly to the time-and-range plotting tried by Wilson in *Vengeance*. Both the second calculator and the range-rate plotter with rate grid patented in 1908 were devised jointly with his brother John. Dreyer's own 'Hints' from 1908 suggest that the principles of the cross-cut were already understood: while it was Norman of *Arrogant* who took the final step of plotting bearings as well as ranges, at about the same time that Dreyer abandoned his attempts to develop range plotting without bearings. Dreyer did not again

[4] Pollen remained in close touch with Rear-Admiral Peirse throughout the second half of 1912, when the ex-ITP was active on his behalf, while also participating in the trials taking place in *Orion*. Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) pp.225-32 and 245.
[5] 'RCAI Recommendation' (*op. cit.*) pp.1-2.

take up rate plotting wholeheartedly until he joined *Vanguard*, after which his first improvised system led directly to the patent of September 1910. Even then, he acknowledged, though only briefly, his debt to Peirse and W W Fisher for the suggestion of the vital clock range pencil. Also, until the adoption of the Anschütz gyro compass, dual rate plotting depended on the Argo mounting as the only source of yaw-corrected target bearings. Yet Dreyer himself must still be credited with the conception of the complete fire control table as an integrated system, combining connected elements for plotting, rate-determination, rate-keeping and range integration.

The 1910 patent was realised by Elliott Brothers as the Original Dreyer Table, which also included a modified Mark VI Dumaresq, the latter embodying the principles which Dreyer had originated early in 1908. However, the initial vague idea of a clockwork drive was dropped in favour of a speed-regulated electric motor with plenty of driving torque (as in the Argo Clock Mark I). Most probably, Keith Elphinstone alone chose a conventional disc-and-roller variable speed drive for the range clock; the same type of mechanism was then used for both the range and bearing clocks of all the subsequent Dreyer Tables. In July 1911, Dreyer proposed that a gyro-compass connection and a bearing clock be added to the almost complete Original Table, but these were not introduced until the next model, the Mark III. Its detailed design was developed from Elphinstone's proposal of October 1911 for the 'Seven Part Recorder', which described the two new features. A motorised relay, controlled from a gyro-compass receiver, applied changes of own course automatically to the Dumaresq. The disc-and-roller bearing clock was connected to the Dumaresq, although the rate was obtained only from the slope of the bearing plot. However, the final Mark III design as constructed in 1912 added the graduated drum, linked to the range clock, by which speed-across from the Dumaresq could be converted to bearing-rate; thus the bearing clock rate could be set from either the Dumaresq or the bearing plot. The dual clock was still not automatic, since both rates were set by hand. However, it was helm-free, in the sense that no change in operating procedure was needed, whether own course was steady, yawing-or turning.

In Decenber 1912, Dreyer submitted his proposal for an additional cone-and-roller drive and step-by-step transmitters and motors, by which he hoped to make the Mark III 'more automatic than at present'.[6] Unfortunately, his ideas were both

[6] Dreyer to DNO, 19 December 1912 in T.173/91 Part III.

impracticable and wrong in principle. However, in the Mark IV Table completed in 1914, Elphinstone did employ electrical means to enable the Dumaresq to set the rates automatically on the disc-and-roller clocks. He also used a cam and lever to convert speed-across into bearing-rate but, although the mechanism was similar to that used in the Argo Clock Mark V, all the surviving evidence indicates that it was designed independently on well-known mechanical principles.

In their judgement on the award, the RCAI stated explicitly that:

> ...the principle and details of the Argo Clock were communicated...and directly contributed to the evolution of the clock mechanism of the Dreyer Tables Mark IV and V. The knowledge so acquired made plain the feasibility of converting the clock mechanism of the earlier types of Dreyer Table into a form which served the same function and was based upon the same principle as the Argo Clock.[7]

At the hearings, they were also at pains to establish what had been communicated in May 1911.

> THE CHAIRMAN: ...on the 15th. May the Mark II sketches...are communicated; the description contains a reference to the addition of a linkage...on the 27th. May sketches of that linkage are sent out.[8]

This can only refer to Argo's initial proposals for the addition of a bearing clock and a dividing linkage to the Argo Clock Mark II. However, no such linkage was used in the Argo Clock Mark III completed in early 1912, while there was a gap of two years before Elphinstone adopted a cam-and-lever in the Dreyer Table Mark IV. In any case, the use of an automatic linkage to set the bearing-rate may have been less important to the RCAI than the general idea of the bearing clock, whether set manually or automatically. The main component of their monetary award was calculated on the basis of £200 per ship, including 24 battleships and no less than 59 cruisers. By 1930, only *Hawkins* had been fitted with a Dreyer Table Mark IV*. Seventeen modern cruisers (plus two aircraft carriers) also had Dreyer Tables, but these were of the Mark III* type, in which the bearing clocks were set manually for rate, using a graduated drum just like that introduced for the Mark III in 1912. It is not possible to say why the RCAI apparently decided to include all cruisers (even those with turret control tables, which did not have a bearing clock):[9] but their generosity ensured that Pollen was rewarded for every ship with

[7] At this point in his copy of the RCAI Recommendation, Dreyer placed a large X in the margin: DRYR 2/2, CC.
[8] T.173/547, Part 18, p.11.
[9] 'Pamphlets on the Dreyer Tables Mark III* and IV* and the Turret Dreyer Table' in 'Guard Book for Pamphlets on Dreyer Tables', AL.

a bearing clock, even if that clock was set manually by means unrelated to that first proposed by Argo in 1911.

Thus the true intentions behind Pollen's award remain, in some areas, obscure. Nonetheless, the Commission concluded, correctly, that the May proposal for the Argo Clock Mark II was the first to communicate the idea of a bearing clock set automatically for rate. Although the judgement is not specific on this point, there can be little doubt that Dreyer's request in July 1911 for the addition of a bearing clock to the Original Table derived from the Argo proposal, even though Dreyer said nothing about automatic rate setting and suggested the use of an unsuitable cone-and-roller drive. Further, since Dreyer's spurious proposal of December 1912 concerned '*additions* which if added to my fire control apparatus would make it more automatic than at present', and the RCAI referred to 'the feasibility of *converting* the clock mechanism of the earlier types of Dreyer Table...upon the same principle as the Argo Clock', they had evidently decided that Dreyer's ideas had been based on the recently completed Argo Clock Mark III for *Orion.* But were they also justified in their stated view that 'the principle and details of the Argo Clock...directly contributed to the evolution of the clock mechanism of the Dreyer Tables Mark IV and V'?[10] And, furthermore, is Sumida correct in his interpretation that, following frequent visits to York, in 1911 Elphinstone plagiarised the design of the Argo clock for the Dreyer Table Mark III: that the 'rates...were..transmitted automatically via a mechanical linkage to the clock': and that 'the clock mechanism bore an unmistakable resemblance to the disc-ball-roller arrangement of the Argo clock'?[11]

From mid-1911, developments by Argo and Elliott brothers proceeded on very different lines. In the Argo Clock Mark III, the rates were transferred mechanically from the Dumaresq to the clocks: though, since the bearing clock was based on a pair of variable-speed drives, there was no need for a special dividing linkage. While this clock was being designed, Elphinstone made his one known visit to Argo at York, specifically to discuss the incorporation of the Anschütz gyro-compass receiver in the Argo mounting. No evidence has been found that he saw any drawings of the clock and he probably did not learn about its internal design until after it was exhibited by Argo in the Spring of 1912. Yet, in the Autumn of 1911, Elphinstone had already circulated his description of the 'Seven Part Recorder'; this incorporated the bearing clock already requested by

[10] Dreyer to DNO, December 1912 and 'RCAI Recommendation'. Present author's emphasis.
[11] *IDNS* (*op. cit.*) p.219.

Dreyer but its rate could only be set, manually, from the bearing plot. In the completed Mark III Dreyer Table, the graduated drum was added as a means to divide speed-across by range; thus the bearing-rate could be obtained from either the plot or the Dumaresq. However, the rate of the bearing clock was still set manually, nor was there any automatic dividing linkage. As in the Original Table, the range-rate was set by following the Dumaresq pointer, while Elphinstone continued to use conventional disc-and-roller variable-speed drives for the two clocks. Thus they bore no resemblance at all to the Argo disc-ball-rollers design. The rival 'Mark III' designs were also different functionally. The Argo transferred rates automatically from Dumaresq to clock: but it was not helm-free, because it could not keep bearings through a turn. The Dreyer was helm-free, since the gyro-compass relay adjusted the Dumaresq automatically irrespective of the ship's course: but, *pace* Sumida, rates were transferred manually, not automatically, to the clocks.

In December 1912, Dreyer made the novel suggestion of using electrical methods to transfer Dumaresq rates; however, the RCAI apparently believed that his other suggestion, to add another variable-speed drive to the Mark III Table, derived from the Argo Clock Mark III, which also used two drives in its bearing clock. Yet, in Dreyer's scheme, the two drives performed different functions, albeit erroneous ones, so it is impossible to say whether his proposal was a botched attempt to avoid or to adapt the Argo design. Whichever was the case, only the general idea of electric transfer had any influence on Elphinstone's design of the automatic Dreyer Table Mark IV, which was not completed until mid-1914, a year after the Admiralty severed all connections with Argo. The two clocks were still conventional disc-and-roller drives, but their rates were set by the Electrical Dumaresq, a device utterly different in principle and detail from anything made by Argo.

On balance, the RCAI may have reached a just decision in rewarding Pollen but not Dreyer. Pollen and Isherwood were the first to describe the principle of a two-rate automatic clock: but one cannot see how the details of their implementation of these principles contributed to the evolution of Elliott Brothers' designs from Mark III onwards. Nor did the RCAI judgement give sufficient credit to Dreyer and Elphinstone for the invention of helm-free operation, which, functionally, was at least as important as automatic, straight-course working. Particularly in view of the dubious method adopted to estimate the value of Pollen's award, his £30,000 does seem excessive. Even so, the

Commission provided no grounds in their judgement for Sumida's view that it was compensation for plagiarism. In any case, to use this highly-charged term betrays a misunderstanding of the process of engineering design and development, especially in the circumstances of two rival teams working on the same problem at the same time for the same customer. Isherwood and Elphinstone both had to depend on other inventions for the data supplied to their clocks and plotters. Both were constrained by the same fundamentals, expressible most concisely in the equations introduced in Chapter 2. They were working within a shared context of contemporary mechanical and electrical technology. Both were aware of earlier and current developments in fire control, notably the Dumaresq linkage and the integrator (based on a variable-speed drive) for generating range from range-rate. Thus, Isherwood (after the false start of the Argo Clock Mark I) began again with the established principle of the Dumaresq-type linkage supplying rate to a variable-speed drive. Then, in only a few months, he made important advances, the perfected slipless drive leading to the conception of the range-and-bearing clock. Dreyer grasped immediately the importance of this new idea and insisted that it be added to the next table design. However, without the Argo slipless drive, Elphinstone could only at first adapt the principle to manual working. He then made the next important advance by coupling a gyro-compass receiver to a modified Mark VI Dumaresq, thereby creating the first helm-free clock, on principles which were later used by Isherwood in the Argo Clock Mark V. Finally, Elphinstone produced his own automatic clock based on the Electrical Dumaresq, a device having no resemblance to anything devised by Argo.

When he was asked to compare the Pollen and Dreyer systems as they existed at the beginning of 1913, James Swinburne FRS wrote of the Argo clock: 'It looks as unlike the Dreyer apparatus as it well could; but it is really on almost the same lines'.[12] This remained true, even after another phase of development of both systems. To plagiarise is 'to take and use another person's...inventions...as one's own'.[13] This is not an appropriate description of the normal process of incremental development followed by both Isherwood and Elphinstone. Both made important innovations. Both made use of earlier ideas, but were always obliged to adapt them to their own purposes. Both ended with automatic, helm-free clocks which solved the fire control equations. Yet, despite the

[12] J Swinburne, *The Time and Range System*, 5 March 1913 in P.1024, AL.
[13] *Concise Oxford Dictionary*.

common principles, their implementations were radically different. Neither were plagiarists; both were original and talented designers.

CHOICES

The Admiralty's choices of technologies and suppliers were necessarily influenced by their technical assessment of the effectiveness and reliability of the devices on offer. However, their decision also had to take account of commercial factors, not only acceptable prices and profits but also the financial stability of the chosen firms. In addition to technical and commercial considerations, there were also personal ones. In the case of fire control, responsibility lay with a few often overworked and under-resourced Admiralty officers, who must inevitably have looked favourably upon firms whose representatives established close and easy relationships with the Director of Naval Ordnance and his assistants.

Apart from the mountings and clocks purchased from the Argo Company in the period before the Great War, the Royal Navy acquired the remainder of its fire control instruments by two well-used means. In the first, a firm developed an instrument using its own resources and then offered it to the Admiralty in an all-but-final form. Service involvement was then mainly with trials to verify suppliers' claims, though the trials might show the need for improvements, to mutual benefit. Such firms were then free to sell their products overseas. Barr and Stroud built their business as a supplier of rangefinders and fire control instruments on this basis. Fire control instruments were also similarly obtained from Vickers, Siemens and Eversheds: also gyro compasses from Anschütz (through Elliott Brothers as their UK agent).

Alternatively, a number of fire control instruments originated as the inventions of naval officers. There were a few unsuccessful attempts to develop such inventions within the Navy (examples were the Vyvyan-Newitt automatic sight and early directors) but, by 1908, the normal course was to protect the invention by secret patent and then place the development in the hands of an outside firm. Firms working on this basis were allowed a reasonable but less substantial level of profits on Admiralty orders, while the Admiralty retained control over commercial exploitation overseas.[14] Thus Keith Elphinstone and Elliott Brothers were following procedures familiar both to themselves and to the DNO's

[14] Admiralty Circular Letter No.61, 1 Jume 1908, 'Rules and Instructions for the Taking Out of Patents by Persons in H.M. Naval Service' in 'Regulations as to Patents' in ADM1/8030.

department when they undertook the development of the Dreyer Tables on the basis of Dreyer's 1910 patent.

In contrast, when the Contracts Department produced their historical record of the Admiralty's relations with Pollen, they began:

> ...This case has been an exceptional one.
> ...Usually inventions of importance for naval purposes...are brought to the Admiralty in a more or less complete state...ready for trial.
> ....
> ...where an inventor brings his invention direct to the Admiralty in an immature state, and wishes the Admiralty to assist in its development, he obviously cannot expect to receive so great a reward if he had borne the expense and risk himself.
> ...Mr. Pollen's case is of the latter class....He brought originally merely ideas worked out partially on paper but without demonstration in the shape of apparatus.[15]

This was true even of Pollen's very first approach to the Admiralty in 1901, which was also characteristic in two other ways. Firstly, although his ideas were not only unformed but not even especially original, he represented them as a secret which the Admiralty should buy. And, secondly, he bypassed the responsible department and went straight to the First Sea Lord and First Lord. It is hardly surprising that, after a similar approach in 1904, the DNO (Captain Barry) was antagonistic. Pollen was fortunate that, in early 1905, Barry was replaced by Jellicoe who, on Harding's over-enthusiastic advice, was prepared to finance the equipment for the *Jupiter* trials (to the tune of £5,300). Pollen then proved unable to complete all the instruments which he had promised: while the rangefinder and plotter which were delivered were almost entirely unsuccessful. As Pollen later admitted, '...no crazier scheme was ever put forward'.[16]

Yet Pollen, with Harding's assistance, continued to impose his ideas on the DNO. His new proposal for a gyro-controlled rangefinder mounting and automatic plotter was certainly novel but, despite the fact that they were entirely unproven, he demanded not only further development funds (and received £6,500) but pressed for an extraordinary contract. This covered only the mounting and plotter and, while it allowed the Admiralty the option of choosing whether or not to place a production order, if they decided to do so they were committed to paying £100,000 to preserve secrecy and monopoly supply. This was an enormous sum, equal to that awarded by a grateful nation to Lord Roberts for turning the tide of the Boer War.[17]

[15] Admiralty, Contracts Branch, *Pollen Aim Correction System. General Grounds of Admiralty Policy and Historical Record of Business Negotiations*, February 1913, p.2 in P.1024, AL.
[16] 'The Gun in Battle', February 1913 in Jon Sumida (ed.) *The Pollen Papers* (London, 1984) p.309.
[17] T Jackson, *The Boer War* (London, 1999) p.143.

The mounting and plotter were completed in time for the *Ariadne* trials in early 1908; although still experimental, the equipment performed reasonably accurately, though probably not always reliably. Meanwhile, in mid-1907, Jellicoe had been replaced by Bacon, who at that time was certainly sceptical of the value of complex fire control instruments. His attitude could well have been influenced by the recent failure of direct sight-setting gear and problems with the early Vickers clock. In any case, the DNO's department faced more immediate and basic problems, particularly the completion of the hydraulic control gear which, for the first time, enabled turret guns to be aimed continuously: and the evaluation of Vickers Follow-the-Pointer sights and transmission gear without which range could not be kept on the sights when the rate was high. Even so, both the early Navy Estimates for 1908-09 and Wilson's initially cordial relations with Pollen show that Bacon was not 'determined from the start to prevent the adoption of Pollen's...system';[18] even Dreyer's intention to 'crab' the gear meant only that it would be rigorously tested. However, Wilson's attitude changed once he had understood the contractual terms demanded by Pollen and that the system was far from complete; he conducted the *Ariadne* trial with the sole purpose of demonstrating that his manual, virtual-course plot was just as satisfactory. Dreyer no doubt provided all the assistance required of him, but his time-and-range plotting was not actually tested until after Wilson had peremptorily terminated the trial itself. Faced with increasing pressures to reduce the estimates, Bacon would not have opposed the decision (permissible under the contract) to reject Pollen's system, though he preferred Dreyer's simple time-and-range plotting to Wilson's over-elaborate scheme. For a Fleet containing but one dreadnought battleship (the *Invincibles* would join during 1908) and equipped to fire accurately only in tactical circumstances which limited range-rate and change-of-rate, this was an adequate first step in the introduction of plotting methods.

More immediate technical priorities and severe financial constraints, Pollen's unyielding attitude, his all-or-nothing contract and the incomplete and experimental state of his system, all combined to deny him his £100,000; though the manner in which he was informed of the decision must be deplored. Yet the Admiralty still chose to pay him £11,500 to fund further development and maintain secrecy: and there is nothing, other than Pollen's later assertions, to indicate that Bacon opposed this policy, in which Pollen

[18] *IDNS*, p.121.

at first cheerfully acquiesced. Not only had Pollen himself made a surplus of £2,930 on his dealings with the Admiralty until the end of 1907, but this payment ensured that the Argo Company, despite development expenses, remained profitable until 1910. At the beginning of 1909, Pollen announced the availability of the complete A.C. system, declaring it to be no longer experimental. Yet, as soon as the Admiralty began discussion on a new trial, it became apparent that some parts were still being developed and others non-existent. Bacon initially wished to order only the redesigned rangefinder mounting; however, despite Pollen's provocations and the fact that the system was at that stage no more than yaw-free, he eventually supported both the purchase of a trial set of equipment (to the value of a further £6,400) and the placement of a production contract. This policy was adhered to by Moore when, at the end of 1909, he took over as DNO at the time when Wilson also became First Sea Lord; the production order for the rangefinder mounting was placed even though it was not yet reliable in shipboard conditions. The contract allowed for an advanced payment of £15,000 and, while the price per mounting was less than Pollen had asked, it was sufficient to cover manufacturing costs, continuing development of the rest of the system (at the same rate of expenditure as previously) and an adequate profit.

The Admiralty placed the order for rangefinder mountings at the beginning of the financial year 1910-1911, before the *Natal* trial of the complete A.C. system in June, 1910. The Mark I clock worked well enough as a mechanism but, unless it was stopped, its true range and bearing could not be altered for change of course or with corrections based on observation; Pollen himself chose to design an entirely new clock beginning with principles already embodied in Service gear. Further, as Pollen admitted, the attempt to convert the straight-course plotter into a true-course plotter had failed; thus, following the Colville report, the only working alternatives for automatically plotting the ranges and bearings from the Argo mounting were rate plotting or straight-course plotting. However, the trial had also demonstrated the problem of obtaining an accurate target speed from either form of course plot: while even Pollen now acknowledged that rate plotting was 'a good alternative...to straight line plotting'. He also declared that, with both methods, 'you must have a steady course'.[19] This was certainly true of straight-course plotting; since the Argo mounting was then only yaw-free, no useful course plot could be made while own

[19] 'The Quest of a Rate Finder', November 1910 in *PP* (*op. cit.*) p.269.

ship was turning. For the same reason, no bearing-rate plot was possible while altering course, but the range-rate plot gave at least an indication of the change in range-rate, and it still allowed comparison between clock range and mean rangefinder range; thus Dreyer had cause for claiming that a Time and Range instrument could cope successfully with continually altering course.

In Moore's later words to Battenberg: 'after the Natal trials all that was successful of the Pollen gear was accepted i.e. The gyro-controlled Range Finder'.[20] At that time, no further choices were required from the Admiralty. Dreyer's new table promised to make best use of the ranges and bearings from the Argo mountings, while its Dumaresq and clock were on proven principles. The Navy could only wait until Argo produced proposals for their new clock and demonstrated, if they could, that true course plotting was, after all, feasible.

By the end of 1911, the Original Dreyer Table had been tried successfully in *Prince of Wales*. Elphinstone was working on the design of the Dreyer Table Mark III, while Argo were well advanced with both the Argo Clock Mark III and their own rate plotter. Both Moore and the Controller (Rear-Admiral Briggs) wished to make a comparative trial of the rival systems, which, in the absence of an Argo true-course plotter, were both based on rate-plotting. Their intention was to order five sets of equipment from each supplier but, despite Moore's efforts, no agreement on terms could be reached with Argo. Probably by June, certainly by August, Moore's patience was at an end. Pollen's intransigence may have been prompted by Argo's financial problems, but his demands for further large payments only drew attention to what the Admiralty considered had been Pollen's extravagance and mismanagement of his company's affairs.[21] Faced with Pollen's own request for the early abandonment of secrecy, his 'prohibitive price' and demands for 'Hush money', Moore recommended that secrecy and monopoly should not be renewed and that, if Argo were to remain an Admiralty supplier, they must operate under normal commercial terms.

[20] Nor was there any lack of commitment in utilising the mounting. From the *Lion* class to the *Iron Duke* class and *Tiger*, it was placed atop the conning tower under an armoured hood which was the focus of the ships' fire control: John Brooks, 'The Mast and Funnel Question' in John Roberts (ed.) *Warship 1995* (London, 1995) pp. 44-53.

[21] There is a marked contrast between Pollen's finances and the prudent policies followed by Barr and Stroud in the early years of their company: M Moss and I Russell, *Range and Vision* (Edinburgh, 1988) pp.24 and 32-3.

At this moment of crisis in their commercial relationships, Pollen's negotiating position was also much weaker because, as Moore explained to Battenberg:

> If there was no other system achieving equal results with Pollens then there would be no choice (or very little) for us; but there is another system; it is almost identical, it is Dreyers.

Plotting was not then the issue; Moore doubted that the new true-course Argo plotter would be a success, particularly at sea in a fleet, but he was still prepared to give it a trial, even before the favourable Boys report was received in the Admiralty. Thus the only immediate technical choice was between the clocks. Moore accepted that both depended on the data supplied by the Argo rangefinder mounting.

> ...Both place data thus obtained upon a clock which...transmits the corrected range...& both clocks keep the rate of clock adjusted as the bearing of enemy alters.
>
> ....
>
> I believe that both Dreyer's & Pollens' [*sic*] systems will produce about equal results - Dreyer's is the more developed at present, but Pollen's workmanship is probably better...[22]

Moore's own writings go no further is differentiating between the functions embodied in the rival designs: but the differences are made clear by Dreyer, with his usual underlinings, in the comparison, written towards the end of 1912, between the Argo and *Monarch* (Dreyer Mark III) clocks.

> In the "Monarch" Clock, alterations in own ship's course are made automatically by the Fore and Aft bar of the Dumaresq being activated by the Gyro Compass.
>
> In the Argo Clock, alterations in own ship's course have to be supplied manually, the operator having first to remember to raise some clips and then remember to lower these clips when ship is steady. If own ship is yawing badly or making small alterations in course for station keeping the manipulation of the Argo Clock will become even more difficult.
>
> ....
>
> If the case occurs...of the enemy disappearing in smoke, rain or fog, and own ship alters course, but the enemy is obliging enough not to alter course or speed while out of sight, there is a far better chance of having the correct range with the "Monarch" table than with the Argo Clock when the enemy reappears....

And, as always, Dreyer emphasised that:

> The "Monarch" Clock can be "Tuned up" throughout to the "Mean Rangefinder Range of the moment" BY INSPECTION.[23]

[22] Pollen to Battenberg, 19 September 1912, MB1/T20/147, Battenberg Papers, University of Southampton (Appendix XVI).

[23] 'Some comparisons made between the Argo Clock and the Fire Control table in "Monarch", n.d. but 1912, T.173/91 Part VII. This is not signed but the style, with its frequent underlinings, is unmistakably Dreyer's.

Of course, the criticisms of the Argo clock were hardly disinterested but they were, nonetheless, justified.

As for the *Monarch* clock, Dreyer made the most of manual transfer of range-rate by claiming, none too convincingly, that it permitted an allowance to be made for 'slip' during a turn. He did not even mention the errors which might arise from the manual, stepwise transfer of range and bearing rates. However, the tests carried out at Elliott's offices in February 1913 were soon to demonstrate conclusively that, at least in ideal operating conditions, manual rate transfer did not result in significant errors, even when rates were changing rapidly. When in December 1912, Dreyer first proposed making his table more automatic, he was most probably chiefly concerned with eliminating the chance of operators' mistakes.

In his report, Dreyer does appear to imply that the bearing rate was transferred from the Mark III's bearing clock only once, as the enemy disappeared; thus Sumida concludes that his claim to keep the range until the enemy reappeared was misleading.[24] However, as shown by the quotations from the operating pamphlet given in Chapter 5, if the Dumaresq's speed-across changed, the clock's bearing rate was altered accordingly. Thus, subject to the limitations of stepwise rate transfer, Dreyer's claim was legitimate.

Dreyer did not draw attention to any other deficiencies of the Argo Clock Mark III; however, since its trials were delayed in part by alterations suggested by naval officers, other problems (particularly that the clock could not transmit spotting corrections and that it always held inclination constant in a turn) must have been well understood in the Admiralty. Nevertheless, Moore persisted with the policy of purchasing five examples of each type of clock for comparative trials. In the Autumn of 1912, he clearly took the view that the pros and cons were finely balanced. But this also meant that there was no longer the need for a relationship with Argo based on monopoly and secrecy. Many years' experience had shown, and the recent negotiation had only confirmed, that the existing contract allowed Pollen to threaten to take abroad not only his own system but what he had learned of Admiralty methods. The longer secrecy was maintained, the more knowledge he acquired. It was time, Moore argued, to break the chains.

If any Board members doubted Moore's interpretation, Pollen himself was soon to provide confirmation by declaring to Churchill that, if his system became public, 'you

[24] *IDNS*, p.232.

have no secret of any kind left in your naval gunnery': and, for good measure, by claiming to have invented rate plotting himself.[25] The Director of Navy Contracts urged that 'the decision already reached be adhered to....Otherwise all experience goes to show that exorbitant terms for monopoly will have to be paid to Argo Company'.[26] Yet the Admiralty continued to discuss the possibility of further orders for the Argo clock on commercial terms, until, in January 1913, Argo at last quoted a price that might well have been acceptable. At that critical moment, Pollen made his final attempt to go over the heads of the responsible departments to the First Lord. This not only exposed his crass efforts to foment discontent in the Service; it also provided conclusive evidence that, even after twelve years, he lacked any conception of how to conduct business with the Admiralty. After this and with the dispute over patents festering, there was little prospect of establishing a new relationship similar to that enjoyed by other suppliers. Involving the Press and inciting questions in Parliament only soured relations further. When the final break was made in the summer of 1913, Argo's name was anathema within the Admiralty.

But, if this were not enough, by mid-1913, the technical choices had also swung further in favour of the Dreyer system. The need to make the Dreyer clock automatic had been recognised, although Elphinstone had not yet begun the new design which would correct Dreyer's initial, faulty conception. The Admiralty had not yet been informed about the Argo Clock Mark V, so they had no reason to change their assessment of the previous Autumn respecting clocks. Argo had indeed completed the prototype Mark IV true-course plotter, but it was never tried by the Royal Navy. This omission could have been due entirely to the worsening relationship. However, the requirements for a plotter had also changed, the developments in rangefinder control making the true-course principle less and less relevant. The Admiralty's willingness to let Dreyer act as one of the judges of his own cause must be deplored, but when he and Usborne set out the case for rate plotting and against true-course plotting in the *Technical History and Comparison*, Usborne ended his concluding 'Summary' thus.

> What we require is a method which gives the hitting range in the shortest time, and which can be relied on to cope with all the difficulties which may arise in action.
> As far as can be seen, Commander Dreyer's Fire Control instrument and system fulfils this requirement completely.

[25] Pollen to Churchill, 21 October 1912 in T.173/91 Part II.
[26] F W Black, 'Argo Company, Present Position' n.d. but late 1912 in MB1/T22/174.

> If no ranges and no bearings are obtainable, then the instrument is suitable for employing estimation only.
> If ranges are obtained, no matter from what range finder, then the instrument makes the best possible use of them, combining the information gained from them with estimation.
> If both ranges and bearings are obtained, then the instrument deduces therefrom the enemy's course and speed with even better accuracy than does the A.C. system.
> If spotting proves impracticable, the instrument is ready for working by mean range finder ranges.

Usborne also pointed out that the Argo system had only 'a continual verbal communication from the plotting table to the clock' and that it was impossible 'to see at a glance if the ranges transmitted to the guns are in accord with those coming down from the range finders'. Furthermore, it had:

> ...no means of applying "meaned" ranges to the clock...only actual ranges....The enemy's speed can only be obtained by measuring on the plot the distance between any two dots or minute circles....one cannot make use of the mean or average position of such dots'.[27]

By 1913, target compass bearings could be obtained from the Argo mounting, which now had a separate trainer to keep it on the target. Thus, in good visibility, frequent bearings could be taken. However, the accuracy of the individual bearings received at the plotter was limited not only by the skill of the trainer, but also by any tendency of the mounting servo to 'hunt', by wander of the gyro-compass induced by turns and roll, and by the rather coarse ¼° transmission steps. Even so, at least every bearing observation could be recorded on the time-and-bearing plot. At the same time, the ranges from the Argo mounting could be plotted automatically by the time-and-range plot, while ranges from turret and other ranges could be recorded manually. In contrast, the Argo true-course plotter could plot only the ranges from the Argo mounting and only the bearings taken simultaneously with these ranges. Consequently, at any moment after plotting commenced, the Dreyer separate range and bearing plots would have more, usually many more, plotted points than an Argo true-course plot. Thus, rate plotting would be the first to yield initial values of range and rates, before any target course and speed could be perceived on the true-course plot. Also, as Usborne noted, speed measurement from the Argo plot had its own additional inaccuracies. Hence, as plotting proceeded, at any moment the enemy speed and course obtained from a cross-cut of rates

[27] Commanders F C Dreyer and C V Usborne, *Pollen Aim Corrector System Part I. Technical History and Technical Comparison with Commander F.C. Dreyer's Fire Control System*, Gunnery Branch, 1913, pp.35-6 and 62 in P.1024, AL.

would be more accurate than the values obtainable from a true-course plot. And, furthermore, only the Dreyer time-and-range plot permitted continuous visual comparison between the ranges predicted by the clock and the mean rangefinder range.

Nevertheless, Usborne had to concede that the usual criticism of rate plotting 'is, in its theoretical sense, true, a time and range plot is always a curve, but the curvature is so slight that in nearly all practical cases it is both negligible and imperceptible'. He also argued that 'the observer always has the knowledge of which way the curve must be bending theoretically to help him':[28] though it would have been more honest to admit that, in the rare circumstances when the range between two ships on opposite courses was at the minimum, the rate could only be determined approximately and would require correction by clock tuning. Also, he did not address explicitly the other causes of curvature in rate plots, alterations of course by own or enemy ship. However, even then, much the same arguments for rate-plotting still applied. If the enemy altered course, the consequent change in range-rate would be perceptible more quickly on the time-and-range plot; clock range and rate could then be tuned as normal. If own ship altered course, the clock rate was adjusted automatically; if the Dumaresq was not already set correctly for enemy course (or even if the enemy altered course at the same moment) clock tuning with the guidance of the range plot kept the clock and rangefinder ranges close together until after the turn was completed, when a new range-rate could be measured and used to adjust the Dumaresq. On the other hand, the disturbances to the gyro-compass and bearing observations caused by any substantial course alteration would have increased the scatter of plotted bearings; thus it must be doubted whether any reliable bearing-rate could be obtained until after the turn had been completed.

Although the functional analysis was restricted to the steady-course case, the technical advice available to the Admiralty in mid-1913 provided sound arguments for the view that, in action, the Dreyer tables, which integrated the rate-plotting and predicting functions in a single, closed-loop system, would be superior to Argo's separate true-course plotter and clock. Furthermore, only the Dreyer was suited to the technique of rangefinder control, then being developed in the 2BS, and to its alternative, rate-control. Its functional principles had worked satisfactorily in the Mark III table, and, although the

[28] *Technical Comparison* (*op. cit.*) p.61.

Mark IV was still being developed, when the time came Elphinstone justified the Admiralty's faith that he could produce a fully automatic, helm free clock.

'The Quest for Reach' has proposed that the Admiralty's decision was also motivated by their expectation of close-range battle against the High Seas Fleet. This suggestion is doubly mistaken. Firstly, two of the main advantages claimed for the Argo system were that rates were transferred automatically and continuously to the clocks: and that true-course plotting produced a straight line even if the rates were changing. Since the shorter the range, the more rapid the change of rates, the Admiralty should have looked more, not less, favourably on Pollen's system if they had really expected to fight only close-range engagements. Secondly, the Royal Navy actually hoped to play at long bowls: though, of course, this would only be possible in good visibility. The rangefinders would then be rather inaccurate: but nonetheless the Dreyer Table would still be able to obtain a mean range, and then a mean range and enemy course and speed, more quickly than an Argo plotter. In poor visibility, fire had to be opened almost immediately the enemy was sighted, using a gun range based on an estimated range or, at best, the mean of a few rangefinder ranges; only the Dreyer Table could cope with such conditions. The Admiralty's decision in its favour did not mark an end to the quest for reach, but a recognition that, unlike the Argo system, the Dreyer was 'a practical instrument designed to meet the real requirements of Naval action',[29] at long range if possible but also at short range if necessary.

Thus, in mid-1913, the Admiralty had compelling reasons for their final choice of Elliott Brothers as their supplier of fire control tables. Under Keith Elphinstone, the firm had built up a close and non-problematic relationship with the Admiralty, beginning with simple instruments like the Dumaresq and progressing to much more complex devices like the Anschütz gyro compass and the Dreyer Tables themselves. They were prepared to develop ideas originated by naval officers and to charge prices with a level of profit acceptable to the Department of Naval Contracts. In return, they were assured of the production contracts and the recovery of their development costs. While Elliott Brothers were in many ways a typical Admiralty supplier, Pollen and his Argo Company were indeed exceptional. This is strongly indicated in the minutes of the Board of Admiralty. These hardly ever mention suppliers, even those as vital to the Navy as

[29] *Technical Comparison*, p.62.

Vickers and EOC. Yet, between 1906 and 1910, Pollen and the Argo Company appear in the minutes of no less than eight meetings of the Board.[30] Pollen's prominence was no doubt partly due to his habit of bypassing the responsible departments and taking his case direct to the First Lord and, indeed, to other politicians, including those in opposition. This behaviour did nothing to develop harmonious relationships with successive Directors of Naval Ordnance. However, most were remarkably tolerant of Pollen's foibles and he received a succession of development contracts as well as the order for rangefinder mountings.

Sumida has proposed that 'the co-operative relationship of Pollen and the Admiralty can be regarded as an early attempt to create the kind of state and private partnership in defence procurement that would later become characteristic of the post-World War II military-industrial complex'.[31] On the contrary, the period before World War I provides many examples of successful co-operation between the Admiralty and private firms,[32] including that with Elliott Brothers who, after World War I, went on to construct the first of the next generation of Admiralty Fire Control Tables. The contrast between Elliott Brothers and Argo is marked. In 1913, the Director of Naval Contracts concluded: 'With regard to...giving encouragement to inventors in the early states of their work [the] Admiralty does adopt that policy in some cases', but in the case of the Argo Company:

> ...the policy was the reverse of successful. Experience shows that there are very considerable advantages in insisting on inventors...getting all the experimental work done themselves and bringing before the Admiralty a finished and prepared piece of practical mechanism instead of a theory worked out on paper only...It may in some cases mean paying a higher price for a good and successful invention.[33]

Likewise, after the War, the experience with Argo was remembered as 'not at all satisfactory and encouraging' and as an indicator of how *not* to conduct co-operative relations.[34] From Jellicoe onwards, Pollen had convinced successive DNOs and

[30] From 1905 to 1913, Elswick and Vickers appear once (31 July 1905) among other firms invited to tender for the *Invincibles*. Pollen or the Argo company are named in minutes for 7 August and 18 September 1906, 31 March and 16 April 1908, 17 and 18 February and 4 March 1909 and 27 April 1910. ADM 167/39, 40, 42, 43 and 44.

[31] Jon Sumida, 'The Quest for Reach: the Development of Long Range Gunnery in the Royal Navy, 1901-1912' in Lt Col Stephen D Chiabotti, ed., *Tooling for War: Military Transformation in the Industrial Age* (Chicago, 1995) p.81.

[32] For the Admiralty's reliance on the research of private firms, see Nicholas Lambert, *Sir John Fisher's Naval Revolution* (Columbia, SC, 1999) pp.152-3.

[33] Report by the Director of Navy Contracts (concerning the Submarine Sound Signalling system invented by J Gardiner) 2 June 1913 in 'Important Questions dealt with by DNO', Vol.II, p.159, AL.

[34] Minute by DNO, 21 March 1919 in 'Ford Fire Control System', p.6 in 'Monthly Record of Principal

Controllers that he should be paid for secrecy and for the development of his system, yet had continued to declare that he possessed unrestricted rights not only to his own initial concepts but to the serviceable instruments developed at Admiralty expense. Towards the end, he even laid claim to Service ideas which he had initially ridiculed. It is a remarkable tribute to Pollen's powers of persuasion that his relationship with the Admiralty, so full of tensions and contradictions, lasted as long as it did. When it eventually ended, the final rupture was largely provoked by Pollen himself.

CONSEQUENCES

The early engagements of the Great War soon established that, in a variety of action conditions, it was difficult to obtain sufficient, accurate ranges before firing began. In the Heligoland Bight, *Lion* opened with an estimated range and relied entirely on spotting to find her targets. At the Falkland Islands, Sturdee's tactics held the enemy at long range but resulted in considerable smoke interference. Rangefinding was difficult and at times impossible and spotting was the main method of range keeping. No plotting was possible in either engagement.

When the opposing battlecruisers met at the Dogger Bank, firing began at unprecedented ranges. An opening deflection was obtained from the bearing plot of *Lion's* Dreyer Table Mark III, even though one of her reports commented adversely on the incomplete elimination of yaw by the Argo mounting. Beatty chose the orthodox lee position but the enemy's smoke and spray, carried by the wind, made ranging difficult, while, for much of the time, the ranges were too high for automatic transmission and the range scales of the plotters. Some improvised manual time-and-range plotting was attempted but proved impracticable.

At Jutland, during both phases of the Run to the South, Hipper's smaller force quickly established gunnery superiority, sank two of Beatty's ships and, most importantly for this study, made at least three times more hits. Yet this decisive result was accomplished with a fire control system which was neither automatic nor helm-free: which used mechanical rather than plotting methods to mean rangefinder ranges: and which relied on rate control when courses were steady, and on rangefinder control when they were changing frequently. The 1SG undoubtedly had an advantage in rangetaking, partly because their stereoscopic rangefinders were inherently rather more accurate

Questions dealt with by DNO', Vol.III, Jan. to Jun.1919, AL.

(particularly at ranges over 16,000 yards or when targets were shrouded in smoke): and partly because their carefully selected rangetakers were better trained than their British counterparts. However, in other respects, the German system was no more elaborate than the Dreyer Table Mark I (which may perhaps have been installed in the two ships of the 2BCS): and considerably less complex than the Dreyer Tables Mark II, III and IV of the 1BCS. Yet, although the Germans were singularly successful without the help of elaborate plotters or range-and-bearing clocks, many historians now consider that the British failed because all but one ship lacked the Argo Clock and none had been fitted with the Argo true course plotter. As Captain Roskill acknowledged, such conclusions are largely conjectural;[35] they are also difficult to counter without further conjecture. Nonetheless, it is hoped that valid historical insights can obtained by addressing three related questions. Firstly, did the actual fire control systems in Beatty's ships add to the difficulties imposed by his tactics? Secondly, did the Argo Clock Mark IV in *Queen Mary* confer an advantage which explains her rather better hitting (3 hits to *Lion's* 2) during the first phase? And, thirdly and more speculatively, might the other ships have been more successful if they had received Argo clocks or the whole Argo system of clock and true-course plotter?

Having sighted the 1SG, at 3.30 Beatty chose to turn E towards their wake, thereby forcing Hipper to turn about; thus by 3.40, the 1SG and the 1BCS were closing at a rate of almost -550 yds/min.[36] Meanwhile, the 2BCS had been ordered to prolong the line astern, but the heel, vibration and large, rapid changes of target bearing induced by their two 16-point turns prevented any ranging until 3.45; even then, they were still forcing their engines at maximum revolutions to make up lost speed, so the rangefinders continued to suffer from severe vibration. As the 2BCS formed up astern, the 1BCS began the starboard turns to form the line of bearing NW; this was intended to clear the smoke which still obscured the view of the enemy from *Tiger* and, probably, *Queen Mary*. At almost the same time, the 1SG turned together to SSE; they opened fire at 3.47, when *Tiger* she was not yet free of smoke; only *Lion* and *Princess Royal* were able to return fire immediately.

During the approach, the courses of the 1BCS and 1SG until 3.45 had been steady and the change of range-rate negligible; also, because both sides then altered course together, the range-rate changed by no more than -70 yds/min. These were

[35] Stephen Roskill, *Admiral of the Fleet Earl Beatty* (New York, 1981) p.192.
[36] As the 1SG worked up to 18 knots, this may have reduced to just over -500 yds/min.

favourable conditions for rate plotting. *Princess Royal*, which had an uninterrupted view of her chosen target, obtained an accurate opening range. Her opening rate (-400 yds/min.) was close to the -340 yds/min. that would have resulted if, after her turn to ESE, the 1SG had still been headed SE. Thus it appears that, before the turn, the Dumaresq of her Dreyer Table Mark III had been set quite accurately for enemy speed and course: in which case the rate would have been reduced automatically by the gyro-compass connection. However, because the 1SG altered course at the same time, the plot of rangefinder ranges remained almost straight and, therefore, would have begun to diverge from the plot of clock ranges. This divergence may already have been detected and the rate made more rapidly closing; however, if so, this initial adjustment was not yet sufficient to correct fully for the enemy's turn.

Had *Princess Royal* been equipped with the original Argo Plotter Mark IV, it would have been useless during the approach, since it could only plot ranges to a maximum of 16,000 yards. However, at the cost of a proportionate loss in accuracy, the gear ratio between the range receiver and the plotting pen carriage could have been altered to allow plotting up to (say) 20,000 yards. Thus modified, it could perhaps have made a true-course plot during the first part of the approach and even continued to plot through the turn to ESE. However, as explained in the preceding section, the initial enemy speed and course would not have been as accurate as that obtained from the rate plots: while, in the turn, the plotted points would have been even fewer and more scattered than before. Even after the turn, it would have been necessary to wait for the new course to become perceptible; then, having measured the new speed (not easy, especially if the target was still regaining the speed lost in the turn), the clock could be reset. In comparison, the points on the time-and-range plot were more numerous and were unaffected by the various bearing errors. A divergence between rangefinder and clock ranges could be detected much sooner than a new course could be perceived on a true-course plot: perhaps even before the target had completed its turn. The difference in slopes indicated immediately whether the rate needed to be increased or decreased; although the full extent of the change was probably not at first apparent, initial changes in range and rate could be applied immediately, in the manner of spotting corrections. Thus range and rate could be tuned progressively until the two plots again converged. In practice, a Dreyer range-rate plot was unaffected by bearing errors and could pick up a change in enemy course more quickly than a true-course plot; in addition, by stepwise adjustment of range and rate, the Dreyer table could keep the clock range and rate in close agreement with the observed ranges.

Princess Royal was the only British battlecruiser to obtain accurate ranges. *Lion's* TS record contains only two rangefinder ranges before fire was opened. Though for different reasons, the four rear ships of Beatty's line were only able to start ranging late in the approach; if any of these ships had taken a few reasonably accurate ranges, its time-and-range plot could have given first a mean opening range and then, a little later, an opening rate. In the short time available as they emerged from the smoke, it is most unlikely that either *Queen Mary* or *Tiger* could have made a useful true-course plot. It might be argued that, since in principle true-course plotting was helm-free, the 2BCS (which was not much troubled by smoke) could have plotted courses as they hauled into line. In reality, their violent manoeuvres prevented the taking of ranges and bearings and must have seriously disturbed the gyro compass, on which the true-course table depended. Furthermore, these older ships were probably supplied from the initial batch of Argo mountings with the air-driven gyro which could only stabilise the mounting against small yaws.

Thus, during the approach, when the purpose of plotting was to obtain first a mean range and then an estimate of enemy course and speed (or the equivalent range-rate and bearing-rate) none of Beatty's ships would have derived any advantage from an Argo true-course plotter. With the exception of *Princess Royal*, their opening ranges were much too high and the rates insufficiently closing: but the errors were due not to the fire control tables but to a dearth of accurate rangefinder ranges.

The 1SG, with much smaller opening range errors, soon began to straddle their targets, forcing *Lion* to lead away in a series of small turns, from ESE to SbyE, which progressively reduced the closing rate. However, the speed-across and its rate-of-change remained low throughout. *Lion's* target bearings shows that her maximum rate of turn was just over 18°/min:[37] from which the maximum rate of change of range-rate can be calculated, using equation III:6, as 256 yds/min/min. Thus, assuming that the rate of her Mark III Dreyer range-clock was altered each time the Dumaresq rate changed by 50 yds/min., the *minimum* time between rate settings was just under 12 seconds. A

[37] 'Record of Events during action of May 31st compiled from records kept in Control Position and Transmitting Station. H.M.S. Lion' in BTY 6/6, NMM.

well-trained operator would have had no difficulty in following with the range-rate pointer. At the maximum rate of turn, equation III:10 shows that the speed-across was changing at -1.65 knots/min. If the rate of the bearing clock was adjusted each time the speed-across changed by 2 knots, the *minimum* time between adjustments was 1.2 minutes; there was plenty of time to convert speed-across to bearing-rate and set the clock accordingly. Thus, in *Lion* and *Princess Royal*, the manual transfer of range-rate and bearing-rate in their Mark III Dreyer Tables should not have introduced significant additional errors. *Lion's* problem was that she opened fire with excessive errors of range and rate on her clock, while her attempts to correct these by large spotting corrections were unsuccessful until 4 o'clock. In contrast, *Princess Royal* began with more accurate clock settings. She then got into *Lion's* smoke but, while this must have interfered with her aiming and spotting, her Dreyer Mark III Table could keep the range and rate when her target, on the beam, was obscured. Unfortunately, before she could make any hits, her fire was also disrupted firstly by shorts and then seriously by hits, especially that which damaged her Argo tower.

Next astern, *Queen Mary* probably made a similar but wider turn to avoid smoke interference. However, she was obliged to respond to each unsignalled turn by the flagship, so it would have been difficult for *Queen Mary's* bridge to give any advanced warning of course changes to the operators of her Argo Clock Mark IV. They were therefore faced with the problem of whether to attempt to manipulate the STEADY-TURNING lever and course clamp as the gyro-compass receiver swung or steadied: or to leave the clock set permanently to TURNING. Probably, the latter was the only practicable method. However, the clock was then only automatic for ranges. The target bearings had to be adjusted continually by hand: either by following the indications of the bearing receiver from the Argo Mounting, or by applying equal but opposite changes to those registered by the gyro-compass receiver.[38] Without the assistance of pointers to follow, these bearing changes were not easily transferred; thus, when faced with a succession of small turns, the Argo Clock Mark IV had no 'obvious superiority'[39] even over the Dreyer Tables Mark III, let alone the automatic, helm-free Dreyer Mark IV in *Tiger*.

[38] The latter was a valid approximation when the speed-across was low.
[39] Roskill, *Beatty* (*op. cit.*) p.192.

Tiger appears to have held longer to EbyS or ESE before also turning further to starboard. Had her Mark IV table been supplied with accurate data, it would have been able to keep range and rates automatically through the subsequent turns, even if the target had been obscured by splashes from enemy shorts. In fact, she too overestimated the range and underestimated the range-rate. Worse, she was soon badly damaged, after which two of her turrets were incapable of firing accurately. *Tiger* was reduced to firing shots raggedly, mostly in ones and twos, thereby making spotting even more difficult and interfering with any attempts to range between shots or salvoes. She also lacked an Evershed installation to take over target designation when the Director appeared to be damaged. These handicaps are more than sufficient to explain her poor shooting for the rest of the battle.

The 2BCS never turned to ESE on the line of bearing, but continued E'wards at full power before making a sharp turn to SSE at 3.54. Until this turn, the calculated range-rate had been almost -800 yds/min. closing. Sumida appears to imply (see Chapter 1) that none of the Dreyer Tables were designed to generate ranges accurately even at half this rate. In fact, the tables with electric drive were constructed for rates up to ±2,000 yds/min. while even the earliest Service model of Vickers clock had a maximum rate of just over ±1,300 yds/min. *New Zealand* and *Indefatigable* both relied on Vickers clocks for range keeping, but no evidence has been found that these instruments were inaccurate once the initial problems had been sorted out by 1909. In any case, *New Zealand's* opening rate was only -200 yds/min. and, while it was progressively increased, it did not exceed -500 yds/min. before the turn. However, high rates undoubtedly caused other problems. Ranging on such a rapidly approaching target must have been difficult, while there would have been a significant delay between making a 'cut' and plotting the range. Unavoidable variations in these delays must also have increased the scatter of the plotted points and the time required to perceive the underlying mean range line. This line was also liable to lag behind the true range, though the error, perhaps 100-200 yards,[40] was small compared with *New Zealand's* opening error of over 2,000 yards. However, because the range-rate was constant, the plotting delays did not result in a rate error, other than that arising from the increased scatter. Clearly, these effects somewhat reduced the advantage of rate-plotting with multiple rangefinders over true-course plotting from a single

[40] If it took 10 seconds to read off a range from a range receiver and plot it, the true range would have fallen meanwhile by 133 yards.

rangefinder. On the other hand, the Argo true-course plotter lacked any provision to read off a mean range, a notable disadvantage when the range was changing rapidly.

When the 2BCS altered course by six points (67½°) to SSE at *3.54*, the component of their own speed along the line-of-bearing altered by 1007 yds/min.[41] The turn may have been completed in as little as two minutes which, if the rate was to be transferred in steps of 100 yds/min. required a rate transfer roughly every 12 seconds. This was slow enough to be practicable even if both ships still had standard Mark VI Dumaresqs, from which the rates had to be transferred manually to the clock: yet it only resulted in a range error of about 100 yards in total. This already negligible error would have been halved if these ships already had the Dreyer Table Mark I with follow-the-pointer transfer of rates from the Dumaresq Mark VI* to the clock. Thus manual rate transfers through the turn did not add appreciably to the larger range and rate errors that had been present as it began.[42]

For the reasons given in Chapter 5, even if the 2BCS had received Dreyer Tables Mark I, these would not have had automatic bearing plots: while Eady's account from *New Zealand's* TS does not mention a manual bearing plot (XVIII-19). Given the conditions of low and slowly-changing bearing rate, it would have been sufficient to open with an estimated deflection based on the Dumaresq speed-across, and then to rely on spotting to keep the salvoes correct for line. Furthermore, whatever the equipment in their TSs, these ships had neither bearing clock nor connection from the gyro-compass to the Dumaresq. However, they had little need of automatic bearing-keeping while the course was steady; while, during turns, the Dumaresq was adjusted by the same methods used with the Argo Clock Mark IV!

After 3.53, all the ships of the 1SG appear to have altered to SE in *Lützow's* wake, causing the rate to change in a few minutes from rapidly closing to opening at about +430 yds/min. (the 1BCS) and +290 yds/min. (2BCS). In the din of action, would Dreyer tables or the Argo system have been better in detecting this change in the enemy's course? Most reliance had to be put on spotting, the Dumaresqs of both the Dreyer Tables and Argo Clocks then being adjusted, on identical principles, according to the spotting

[41] Calculated from the data in Note XXVI-14.
[42] *New Zealand's* 'Record of Ranges, Rates, etc...', 8 June 1916 (in ADM 116/1487, PRO) is contradictory in that a hand-written addition for *3.55½* gives the rate as '350 Cl.' but the gun range reached its minimum (10,800 yards) at *3.56* i.e. its rate was then momentarily zero. The next recorded rate was 'Nil' at *3.58½*.

corrections for range-rate and deflection. While deliberate, spotted salvoes were being fired, it was also possible to range in the gaps and so continue plotting although, with the enemy firing back, the rate and accuracy of ranging was likely to be reduced. Thus, as in other circumstances, the Dreyer rate plot, by comparing clock and rangefinder ranges, could detect a change of course more quickly than a true-course plot. This comparison assumes, of course, that, while firing, bearings could be taken with sufficient accuracy to make a useful true-course plot: which is by no means certain. Furthermore, true-course plotting was always dependent on one, stabilised mounting and, as shown by *Princess Royal's* experience, could be stopped entirely by a single hit or breakdown.

The second phase of the Run to the South began when the 5BS opened fire on the rear German ships. At about the same time (approximately 4.10) Hipper turned to SbyW. Until 4.27, the only subsequent disturbance for *Lützow*, *Derfflinger* and *Seydlitz* was the change in formation to line ahead S at 4.18: but *Moltke* and *von der Tann* were also forced to zig-zag to avoid the accurate, long-range fire of the British battleships. After the hit on Q turret, *Lion* had veered out of line to starboard but she then recovered to a course due S, with the rest of Beatty's force to port. In this second phase, the British ships were almost certainly at a disadvantage in terms of general visibility and the conditions for rangetaking; they also remained to windward of their opponents and would again suffer from interference due to their own smoke if they did not maintain the appropriate line of bearing.

Once *Barham* had commenced firing, Beatty turned *Lion*, still without signals, to course SE, which induced a rapid closing rate a little over -710 yds/min; thus the 1SG were soon able to resume firing. Then at 4.20, *Lion* altered away to SSE, thereby halving the rate; however, the speed-across remained low (see figures in Chapter 2). *Princess Royal* and *Queen Mary* turned directly to SSE; *Tiger* and *New Zealand*, which were initially rather closer to the enemy, appear to have turned later to follow their consorts. Despite three early hits by the British, the 1SG soon found the range and rate and regained gunnery superiority. The concentration by *Derfflinger* with *Seydlitz* produced a weight of accurate fire on *Queen Mary* which no British battlecruiser could long withstand. It is hardly surprising that, after she blew up, the British line was thrown into confusion but, almost immediately, Hipper turned sharply away, though his withdrawal was not detected by most British ships for some time.

For this second phase, it is necessary to focus mainly on *Lion*. She was already under fire before she turned to SSE. Thus she needed to have formed a reasonably accurate estimate of *Lützow's* course and speed during the SE'ly leg in order to keep the range and rate through the turn. The calculated changes in range-rate and speed-across during this turn, which lasted about 2 minutes, were some 450 yds/min. and 2¼ knots, respectively. Thus transfer of range-rate in steps of 50 or at worst 100 yds/min. was practicable: while the bearing-rate required at most two 2-knot adjustment. Consequently, the clock and Dumaresq of her Mark III Table could keep the range and rates satisfactorily through the turn; the problem was determining the initial enemy speed and course. *Lion's* TS record contains only two ranges while her course was SE, though both were misleadingly high;[43] nonetheless, had they been used to plot (or even to calculate) a rate, a value of -500 yds/min. would have been obtained. Despite the difficulties of making a useful bearing-rate plot, it could at least record every bearing taken and provide an approximate mean rate. Then by setting the Dumaresq by a cross-cut, the resulting enemy speed and course would not have been too far from the correct values. Alternatively, the same two ranges, with simultaneously-taken bearings, might have been used on a true-course plot, *provided both ranges had been taken with the Argo rangefinder*. However, there was then no averaging out of bearing errors over many observations; thus, typically, any enemy course and speed from a true-course plot must have been less accurate than the values obtained with a cross-cut of plotted rates.

Unfortunately, despite the indication from the rangefinder ranges and the need for repeated large DOWN spotting corrections, *Lion's* TS was still using a rate of only -200 yds/min. as the turn commenced. Thus the enemy course on the Dumaresq was insufficiently converging, an error which was then maintained through the turn. However, this was a failure to make use of the available data, not of the Dreyer Table.

Since ranging in all Beatty's ships was now handicapped by worsening visibility, the same considerations suggest that none would have benefited from true-course plotting. *Princess Royal's* Dreyer Table Mark III could adjust automatically as she attempted to follow her flagship's turns to SE and SSE. However, her gun ranges (which are only an approximate guide) indicate that she did not adopt a sufficiently rapid closing rate until well after the second turn. Her Argo rangefinder remained out of action, while her

[43] *Lion*, 'Record of Events' (*op. cit.*).

ranging certainly suffered interference at times from *Lion's* smoke; probably, *Princess Royal* was forced to rely mostly on spotting and could do little if any plotting.

Queen Mary also had to respond as best she could to the course alterations of those ahead, so the operators of her Argo Clock Mark IV may or may not have received advanced warning of her own turns. Whether the clock's control lever was set to STEADY or TURNING, there was a risk that they would not realise quickly enough that a change registered by their gyro-compass receiver actually signified the start of a turn rather than a brief yaw. If the lever was at STEADY, there would have been a further delay while the angle-between-courses was unclamped and the lever thrown over. Once again, given these operational dilemmas, the Argo Clock Mark IV was at a disadvantage compared with the helm-free Dreyer Tables Mark III and IV.

The courses of *Tiger* and *New Zealand* cannot be determined with any accuracy but, until *Queen Mary* blew up, they appear to have been steadier than those of the leading ships. Thus the changes in rate were smaller and could have been easily accommodated, not only by *Tiger's* automatic, helm-free Mark IV table, but also by *New Zealand's* fire control installation, even if it still depended on manual rate transfer from Dumaresq to Vickers clock. *Tiger* continued to be handicapped by the damage to her turrets, while *New Zealand* probably suffered from smoke interference, as would be expected from her windward position. In both ships, the ranges were too high before *Queen Mary* was lost but, especially in *Tiger's* case, too low afterwards. Without accurate ranges, no fire control table, from the simplest to the most automatic, could achieve very much.

This analysis of the two phases of the Run to the South provides clear answers to the three questions posed earlier. Firstly, the functional characteristics of the Dreyer Tables did not add appreciably to the difficulties experienced by Beatty's ships. The root cause of their problems was that, with the single exception of *Princess Royal* during the first approach, they were unable to obtain sufficient, accurate ranges. In both phases of firing, the speed-across remained low. Especially in such conditions, rate plotting could make the best use of the few available ranges; while the errors introduced by the manual transfer of rates were insignificant. Only two provisos are necessary. Firstly, if the 2BCS had not already been supplied with Dreyer Tables Mark I, they would have found range-plotting, by manual means, rather more difficult than the other British battlecruisers. And, secondly, the errors due to manual rate transfer were minimal only while the operators did not make mistakes.

Secondly, *Queen Mary* derived no special advantage from her Argo Clock Mark IV. In fact, Beatty's unsignalled turns, which were especially frequent in the first phase, made it difficult to use the clock except in the TURNING mode, which required the continual unaided transfer of target bearings from Argo or gyro-compass receivers. Except that range-rate was transferred automatically, in other respects this mode of working was no different from that used with the Dreyer Table Mark I. During the first phase, *Queen Mary* actually made only one more hit than *Lion*, whose TS record suggests that her fire control personnel were unable to establish enemy range and rate with any certainty. *Queen Mary's* shooting, which was unremarkable by German standards, did not need to achieve much to improve on the flagship's score; the additional hit can be explained by the better ranging and spotting that would be expected of the BCF's crack gunnery ship: and because, if her survivors remembered correctly, she was not badly hit until later.

In addressing the third question, the first conclusion must be that none of Beatty's other ships would have been more successful if, like *Queen Mary*, they had been given Argo Clocks Mark IV. Even if they had been equipped with the Argo Clock Mark V (which was both automatic and helm-free) in conjunction which a Dreyer rate plotter, they would have been no better off than *Tiger*, which had the functionally similar Dreyer Table Mark IV. Thus the only installation that might have demonstrated a decisive superiority was the final, complete Argo system of Mark V clock and Mark IV plotter, although any improvement would have to be attributable to the plotter alone. However, this analysis has not found any moment in the Run to the South when an Argo true-course plotter would have given results as satisfactory as those actually obtained from the Dreyer rate plotters. If the Royal Navy had adopted the full Pollen system, Beatty's ships would probably have made their first hits even later than was actually the case: and it would certainly not have enabled them to hit before they were hit in return.

The shooting of other British ships at Jutland was much more satisfactory and can be explained by their adherence to the same basic method. Before opening fire, it was necessary to obtain some reliable ranges, preferably sufficient to plot and to obtain a mean range and rate; exceptionally, *Iron Duke* was even able to obtain a spread of ranges to indicate the size of her opening bracket. On opening fire with deliberate salvoes, the remaining range errors (and, if possible, rate errors) were corrected by spotting while, as soon as the target was straddled, rapid fire was essential before the target was lost, usually because it disappeared into the murk. This simple system (which, apart from the different method of meaning ranges, was the same as that used by the 1SG) could be followed by all the British capital ships, irrespective of their fire control gear. While *Iron Duke* demonstrated that range plotting could yield valuable data, no battleship is known to have obtained useful results from the bearing plot. Of course, this also meant that, in the poor visibility which set in soon after the Run to the South, true course plotting would have been impossible.

As might be expected from the preceding conclusions, after the Battle of Jutland no blame was attached to the Dreyer Tables for the defeat of the BCF or the inconclusive result of the brief clashes of the battlefleets. By the end of the War, it was accepted that the original Dreyer bearing plot had rarely proved useful, but the GDT gear gave a new importance to the plotting of bearings (now from the Director itself) and to the bearing clock. The Dreyer Table Committee had every opportunity to be critical. They did, indeed, record their concerns about slippage in the range clock: although this problem was recent and confined to tables with additional experimental fittings. They confirmed the value of the range plot as a source of meaned ranges, but considered that, in action conditions, it could hardly ever be used to obtain a rate. Instead, they recommended a cross-cut of bearing rate with inclination, as measured by the then new and largely untried inclinometer.

In their recommendations for a new generation of fire control tables, the Committee discussed true-course plotting, but decided that the enemy's track could be plotted accurately only in such favourable conditions that plotting would be unnecessary. However, they acknowledged the superior design of the Argo slipless drive, which was incorporated in the clock of the new Admiralty Fire Control Table. By the Spring of 1923, the limitations of the inclinometer were better understood and it had been accepted that inclination was not an alternative, but complementary, to range-rate. The completed AFCTs were, compared with the older Dreyer Tables, instruments of extraordinary sophistication, in which, as far as possible, gun range and deflection were generated automatically. Yet they still embodied the same principles of an integrated system which plotted ranges and bearings separately against time. The observed rates were used, now with inclination as well, to set or adjust the estimates of enemy speed and course: while the plots allowed the predicted ranges and bearings, as generated by the clocks, to be compared graphically with observed values. Their clocks were based on mechanical designs originated by Argo and Ford: but, as fire control systems, they were highly developed Dreyer Tables.

CONCLUSIONS

With good reason, Professor Sumida has placed his accounts of Arthur Pollen's dealings with the Royal Navy among the 'new model monographs', which are 'based on the use of a wide range of previously unexploited sources' and directed towards 'the integrated examination of the technical, personnel, economic, administrative, and financial factors in order to reinterpret the course of policy-making and its consequences in operations'.[44] Even so, events and technical assessments are described largely from Pollen's viewpoint, that of a struggling inventor battling to overcome the Admiralty's parsimony and technical conservatism and the opposition of the responsible officers, Bacon and Moore in particular.

The present thesis has tried to show that the Admiralty's perspective was very different, of a repeatedly over-optimistic promoter who often delivered late or not at all, regularly demanded large sums for his inventions, and threatened to take his (and, later, the Admiralty's) secrets abroad if he did not get his way. Extensive use has been made of an important source which has not been cited in earlier works: the RCAI files in the Public Record Office.[45] They include, amongst the evidence for Pollen's first, unsuccessful appearance in October 1923 (which has not been described previously), Argo's own financial statement; this establishes that Pollen himself, unlike his shareholders, was well rewarded over many years for his work on fire control, even before he received the overgenerous award from the RCAI in 1925. Further, despite a considerable overlap with the Pollen Papers, these RCAI files also contain many essential Admiralty documents, including those relating to the development of the Dreyer Tables. This study has also

[44] J T Sumida and D A Rosenberg, 'Machines, Men, Manufacturing, Management and Money...' in John B Hattendorf (ed.) *Doing Naval History, Essays towards Improvement* (Newport, RI, 1995) p.30.
[45] The evidence bundles for the RCAI hearings in 1923 and 1925 are in T.173/91, with additional material in T.173/88-90. The Minutes of Proceedings are in T.173/547; Parts 1 to 3 cover the hearings from 9 to 11 October 1923.

drawn on surviving technical documents (e.g. handbooks, reports, patents British and American) and on the Admiralty records which chronicle the development of long range gunnery in the Royal Navy after 1900.

These sources have been invaluable in clarifying the relative chronologies for the development of the three British fire control systems and in attempting objective comparisons of their technical characteristics. Firstly, there was the initial Service system which, although far from automatic, introduced many of the essential instruments. Their capabilities, and the different ways in which they were invented and procured, establish the technical and administrative context against which the rivalry between Pollen and Dreyer, Isherwood and Elphinstone, and Argo and Elliott Brothers, was played out. The second system is Pollen's AC. The designs of the various clocks and plotters have been considered in sufficient detail to establish their actual functional characteristics and limitations, as opposed to Pollen's sometimes misleading claims. Also, the Admiralty's long and frequently stormy commercial relationship with Pollen has been contrasted with their generally easy and informal dealings with other supplier companies, including Elliott Brothers. Thirdly, the chronological development of the Dreyer tables, the principal characteristics of the different marks, and the inventions contributed by Dreyer himself, Elphinstone and others, have been described in more detail than previously,[46] though some aspects unfortunately remain obscure (particularly the installation dates for the Mark I tables).

With the aid of this technical chronology, quite different conclusions have been reached from those of previous authors quoted in Chapter 1. In certain respects, the AC system was developed from, or at very least was anticipated by, Service ideas. Even so, Argo were certainly first to propose the idea of a bearing clock. Yet there was no similarity, either mechanically or in the manner of use, between the methods they and Elliott Brothers devised to transfer the Dumaresq speed-across and convert it into bearing-rate: nor was there at any time a resemblance between the Argo and Elliott variable speed drives. Thus there are no grounds for accusing Elphinstone of plagiarising Isherwood's design: not least because, almost certainly, he had no opportunity to do so. As for the choices made by the Admiralty, for many years, despite Pollen's many provocations, they continued to fund his developments and to purchase equipment. The

[46] For a recent account of the Dreyer Tables, though only as described in the 1918 handbook and 1930 pamphlets, see William Scheihauf, 'The Dumaresq and the Dreyer' in *Warship International*, No. 3, 2000.

crisis of 1912 followed Pollen's refusal, when faced with a financial crisis of his own making, to accept orders for clocks to participate in competitive trials. By that time, the Argo design (the Mark III Clock) was no longer decisively superior to the clock in the Dreyer Table Mark III; the Argo was automatic only on steady courses, while the Dreyer was helm-free even if its rate transfers were manual. Moore persisted with his intention to hold trials, but recommended that Argo be treated in future like other suppliers. This might still have been possible, until Pollen himself provoked the final rupture by demonstrating conclusively that a new relationship on commercial terms was unsustainable.

Wherever possible, the comparisons between the technical and functional characteristics of the competing clocks and plotters have been supported here by quantitative analysis. It has been possible to show that the errors inherent in the mechanism of the Vickers clock were unimportant: that the stepwise, manual transfer of range-rate from the Dumaresqs to the clocks of the Dreyer Tables Mark I and III did not introduce significant errors: and that there was time enough for the two-stage manual process for setting the rate of the Mark III's bearing clock. This quantitative approach has also been extended to the Run to the South, although it has also been necessary to go back to the primary sources for the battle in order to understand properly the impact of Beatty's tactics. It has been concluded that the rates were not too high nor were they changing too rapidly for any of the Dreyer Tables: that, because *Queen Mary*, like all those astern of *Lion*, had to follow the flagship's unsignalled changes of course under fire, she obtained no special advantage from her Argo Clock Mark IV: and that the shooting of Beatty's battlecruisers would not have been better if they had been equipped with the Argo system. They twice lost gunnery superiority because, except for *Princess Royal* during the initial approach, they lacked sufficient, accurate ranges. This was mainly due to Beatty's headlong tactics and to the worsening visibility from the British ships in the second phase; however, *Lion's* record, in particular, suggests that inadequate training of rangetakers and fire control personnel was also a deciding factor.

By the end of the Great War, it was clear that real actions placed far greater demands on fire control than had been anticipated before the conflict: either by the British or German navies, or, indeed, by Dreyer or Pollen. In good visibility, firing began while ranges were still too long for accurate rangetaking and bearings could not be measured precisely. In bad conditions, it was necessary to open fire almost as soon as the enemy was sighted, with at best a few snap ranges as a guide. As soon as salvoes fell close to a ship, it would invariably take evasive action; thus, while the fire control system must be helm-free to correct automatically for changes in own course, it must also be able to detect quickly any alteration by the target. For the new generation of fire control tables, the Royal Navy accepted the superiority of the Argo-pattern variable speed drive as the basis for the range-and-bearing clock: but they remained convinced that the clock must be part of an integrated table which plotted ranges and bearings separately and permitted the predicted ranges and bearings to be compared continuously with observations. Thus the clock could be tuned to give better predictions while courses were steady and it could be adjusted in response to alterations by the enemy. This 'closed-loop' principle, first introduced (though for range only) in the Original Dreyer Table, was much better suited to action conditions than the 'open-loop' Argo system, in which the true-course plotter and clock remained separate, unconnected units. Before opening fire, rate plotting was able to use every observation of range or bearing, however imperfect. After firing began, only rate plotting could complement spotting in determining the best step-by-step adjustments to range, deflection and range-rate which would first find and then hold the target, even as it attempted to evade the straddles and hits.

The Admiralty's choice of the Dreyer Tables, as manufactured for them by Elliott Brothers, was amply justified by wartime experience. The tables (of different marks, automatic and manual) were able to cope with the rates and change of rates encountered at Jutland: and, while the gunnery of the battlecruisers was disappointing, it was not made worse by the Dreyer tables, nor would it have been improved if the ships had been fitted with the Argo system. Later in the War, the Dreyer Tables proved adaptable, in ways inconceivable for the Argo designs, to the new fittings demanded by the lessons of action. And, although the next generation of fire control table used Isherwood's variable speed drive, their system principles were the same as their direct predecessors, the Dreyer Tables.

ADMIRALTY AND INDUSTRY

The history of the Royal Navy's gunnery in the early years of the twentieth century has been unduly dominated by two individuals, Percy Scott and Arthur Pollen who, though for different reasons, detested the Admiralty and left images of an organisation profoundly hostile to technical innovation. The present author has shown elsewhere that Scott's account of the history of the Director is seriously distorted and that its development was not, as is usually represented, a case of too little, too late: but of successful innovation against considerable technical obstacles.[47] This study has shown that the Admiralty was prepared to support Pollen over many years and to treat him and his company as a quite exceptional case. The final breech with Argo did not follow the perverse rejection of a technically superior fire control system; it was the result of reasoned choices between two systems offering distinct functionality: and between two suppliers with very different commercial relationships with the Admiralty.

The revolution in gunnery from 1899 to 1914 required the development of many new instruments. Like the Director, and, indeed, the Dreyer Tables, these were produced by industrial firms working closely with the surprisingly few members of the Department of the Director of Naval Ordnance who were responsible for the procurement of new fire control instruments. The relationship between the DNO's department and British instrument makers and weapons suppliers was, in general, close and relatively informal. It depended on much of the research and development being carried out by the firms, the Admiralty itself having neither the organisation, personnel nor funds for these activities. Its ideal was to encourage suppliers to compete on both technology and price: though the danger of reliance on a monopoly supplier was always present. On the whole, British industry was able to meet the Admiralty's requirements, though occasionally by bringing in technology from abroad (some early fire control instruments and gyrocompasses). Nonetheless, at the outbreak of the War, the Royal Navy led the world in directors, while, as far as is known, no other navy had fire control plotters and predictors as sophisticated as the Dreyer Tables Mark IV. Once the United States entered the War, Admiral William S Sims found:

> ...a number of things...in the Grand Fleet in which we are very distinctly inferior. This includes such fundamentally important things as fire control, concentration and so forth....the British are very distinctly in advance of us in their application of electricity to fire control.[48]

Thus, the fire control instruments developed in the pre-War years were not examples of the 'defective technology, reflecting the scientific and technical backwardness of British

[47] John Brooks, 'Percy Scott and the Director' in David McLean and Antony Preston (eds.) *Warship 1996* (London, 1996) pp.150-170.

[48] Michael Simpson (ed.) *Anglo-American Naval Relations 1917-1919* (Aldershot, 1991) p.330 (reference courtesy of the editor).

industry': nor were they an 'ingredient in the British failure to annihilate at Jutland'.[49] On the contrary, the achievements of the Admiralty's suppliers only add to the case against declinist theories of British industry.[50]

Of course, the co-operation of Admiralty and British industry was not always successful. The most notable failure, which is outside the scope of this study and complicated by the divided responsibility between the Admiralty and the Ordnance Board, was in the provision of armour-piercing shell.[51] In fire control, the worst failing was the delay in adopting the more accurate 15-foot rangefinder. However this was not the fault of the supplier (Barr and Stroud) but of the Admiralty, which did not order the latest models soon enough. This lapse was probably due principally to the flawed structure of the pre-War Admiralty. There was no part of the organisation responsible for representing the interests of users of weapons and instruments against those of the supplier departments reporting to the Controller. The user role was performed, though in no systematic way, by the Inspector of Target Practice and by the fleet Commanders-in-Chief. Their criticisms and demands sometimes stimulated improvements or the adoption of new instruments. However, until the creation of a proper naval staff, the Controller's departments had, as best they could, to identify requirements, procure the equipment and, with the assistance of Gunnery and Torpedo Schools, assess its performance. It is interesting, in view of his involvement (in several ways) on the supplier side, to find Frederic Dreyer as the first holder of the staff post of Director of Naval Artillery and Torpedoes: and to observe the opposition of Beatty to the reduction of his prerogatives, as Commander-in Chief, Grand Fleet, to represent the gunnery user afloat.

The self-interested accounts by Scott and Pollen have served to obscure much of the Admiralty's encouragement of innovation and its normal and productive relationship with British industry. Without their distorting influence, it may now be possible to develop a better understanding of this relationship in the pre-War period, how it changed during and after the Great War, and to explore and explain its successes and failures in the period leading up to the next World War.

[49] Correlli Barnett, *Engage the Enemy More Closely* (New York, 1991) p.7. See also *IDNS*, p.337.
[50] For a comprehensive study and the sources for an anti-declinist account, see David Edgerton, *Science, technology and the British industrial 'decline', 1870-1970* (Cambridge, 1996).
[51] Arthur Marder, *From the Dreadnought to Scapa Flow, Volume III* (Oxford, 1978) pp.204-7. Guy Hartcup, *The War of Invention* (London, 1988) pp.49. Iain McCallum, *The Riddle of the Shells 1914-1918* (unpublished study) and 'Achilles Heel? Propellants and High Explosives, 1880-1916' in *War Studies Journal*, Vol.4, Issue 1, Summer 1999, pp.65-83, copies courtesy of the author.

APPENDICES

Appendices to Chapter 2

APPENDIX I

TIME-AND-RANGE HYPERBOLA

1. From the viewpoint of observers in the firing ship, the enemy appears to be following an apparent or virtual course which can be found by a vector subtraction (with a triangle of velocities) of the firing ship's velocity from the enemy's velocity: see Fig. 2.6. The virtual speed v is found from:

$$v^2 = e^2 + s^2 - 2es\cos\theta \qquad \text{(I:1)}$$

where θ is the angle between courses,

and e and s are the speeds of the enemy and own ships.

2. Thus v is small when the angle between courses is small and rises to a maximum when courses are opposite.

$$v = e - s \text{ when } \theta = 0°$$

$$v = e + s \text{ when } \theta = 180°$$

3. With reference to Fig. 2.6, from the right triangle SPE:

$$R^2 = R_0{}^2 + (vt)^2 \qquad \text{(I:2)}$$

where $t = 0$ when $R = R_0$, the minimum range between the two ships.

4. Equation I:2 can be rearranged into the standard hyperbolic form:

$$\frac{R^2}{a^2} - \frac{t^2}{b^2} = 1$$

where $a = R_0$ and $\qquad b = \frac{R_0}{v}$

Since the slopes of the asymptotes of the hyperbola (when drawn as in Fig. 2.7) are $\pm\frac{a}{b}$,[1] the slopes of the asymptotes to the time-and-range hyperbola are $\pm v$.

5. Thus, for given values of e and s, when courses are opposite the slopes are a maximum; and, when courses are parallel, the slopes are at a minimum. If courses

[1] E A Maxwell, *Elementary Coordinate Geometry* (London, 1954) pp.163 and 166.

and speeds are identical, the asymptotes and the hyperbola itself are all horizontal lines.

6. If courses converge towards or diverge from a common point, R_0 is zero. Thus the hyperbola coincides with the asymptotes. In practice, the ranges in action are all well before or well after the minimum range point. Thus, provided that courses remain steady, the time-and-range curve is a straight line i.e. the range-rate equals the virtual speed, which is along the line-of-bearing.

APPENDIX II

BRACKETS

1. If the range-rate was correct, the range on the range-clock changed at the same rate as the correct target range. Thus a bracket could be worked as if the range were constant and the target would be straddled by one of the salvoes of the bracket.

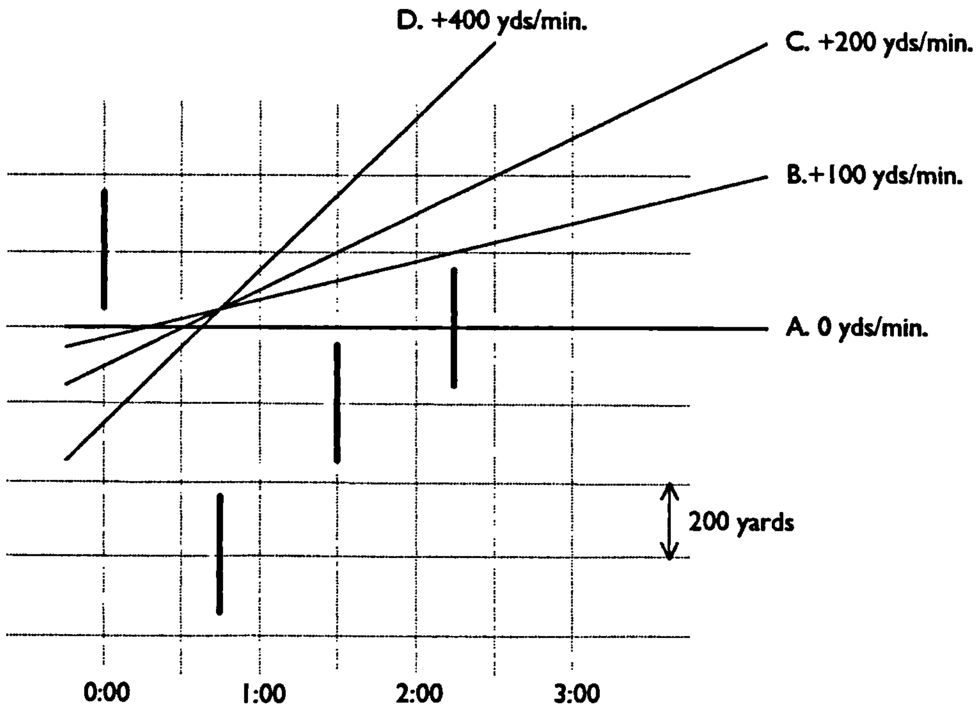


FIG. II.1: BRACKET MISSING DUE TO RATE ERRORS

2. The figure is a graph of range against time. The vertical axis represents the actual range on the range-clock *minus* the change of range due to the constant clock rate. Thus only the spotting corrections are shown and the diagram appears identical irrespective of the rate in use. The horizontal axis is graduated in minutes. The

vertical bars represent the spreads of salvoes fired in a typical bracketting pattern at intervals of 45 seconds. The salvo spread is 300 yards.

3. Line A represents a target with a range-rate equal to that set on the range clock; thus the line is horizontal. If the centre of the first salvo falls over by 150-250 yards, the target is not straddled until the fourth salvo.

4. Line B represents a target with a range-rate 100 yds/min. greater than that of the clock. Despite the small difference, the bracket fails to straddle the target. B is representative of a set of parallel lines; for each line, the first salvo must fall over and the fourth short. Thus the band containing these lines is only 125 yards wide.[1]

5. Similarly, lines C and D are representative of targets with rate differences relative to the clock of 200 and 400 yds/min. Their respective bands, at 350 and 700 yards, are considerably wider.[2] This shows that, as the difference between the clock and target rates increases, there is an increase in the spread of target positions which:
   a) are consistent with this pattern of salvoes and
   b) result in the bracket failing to find the target.

6. If a bracket, although worked to completion with a final correction of UP or DOWN 200, failed to straddle, the clock rate must have been wrong. Thus subsequent spotting corrections for range had to be accompanied by corrections for rate. However, the *Manual of Gunnery 1915* (in force when Jutland was fought) only made specific recommendations on rate corrections after the target was successfully straddled:

> The size of the rate correction to be used before straddling must be pre-determined on the knowledge of the probable error of the rate under the circumstances obtaining at the time of opening fire.
>
> ....
>
> After straddling, a simple rule of thumb for keeping the rate is to accompany every spotting order required by a similar rate correction of half the amount of the range order.[3]

7. Was there an equivalent rule of thumb to find the target even if a bracket failed to straddle? The following case study is based on the problems facing the BCF when fire was opened at the start of the Run to the South: namely, that most ships were

[1] The band width is measured along the vertical line for time = 0:00.
[2] For each D line, the first salvo must fall over and the *third*, short.
[3] Admiralty, Gunnery Branch, *Manual of Gunnery (Vol. III) for His Majesty's Fleet 1915*, p.15, Ja 254, AL.

using ranges that were too high and a closing rate that was too slow i.e. insufficiently negative. If the range was too high, the initial salvoes would be OVER; normal procedure was then to fire successive salvoes with corrections of DOWN 800 until a salvo fell short, that is, the target was crossed. The next salvo was then UP 400; if it fell OVER (as was likely with a closing rate), the bracket was completed with a salvo DOWN 200.

8. However, as shown in Fig. II.2, if the target's rate was more negative than the clock's, even by as little as 100 yds/min., the bracket could be completed without straddling the target. As in the previous figure, representative lines have been drawn for rate differences of -100, -200 and -400 yards per minute. Is there a single rule which, for all these rate errors, can find the target and correct the rate reasonably quickly?

9. Initially, it was assumed that, if the final two salvoes of the bracket were both OVER, subsequent corrections should by DOWN 200, CLOSE 100 (reduce the clock range by 200 yards and the clock rate by 100 yds/min.). It was found that this procedure was too slow at correcting the larger rate differences. If the rate difference was -400 yds/min., the target was not straddled until six more salvoes had been fired after the final salvo of the bracket i.e. six minutes after crossing the target.

10. The effects of a repeated correction by DOWN 400, CLOSE 200 were than calculated. This was found to be too drastic for rate, which tended to be already too rapid by the time of the first straddle.

11. DOWN 400, CLOSE 100 was then tried. The results are illustrated in Fig. II.2 and the range sequences for the three initial rate differences are also tabulated overleaf.

12. When the rate difference was -200 yds/min., the target was straddled by the first salvo after the bracket. However, one subsequent normal correction (of DOWN 200, CLOSE 100) was also needed before the rate was fully corrected.

13. If the rate difference was -400 yds/min., the third salvo after the bracket straddled but, again, the rate was not fully correct until the next-but-one salvo went over, necessitating a normal correction.

Salvo time	Range relative to crossing salvo yards	Spotted as	Spotting corrections		Total change in rate yds/min	Range change due to rate yards	Remarks
			Range yards	Rate yds/min			
0:00	+800	Over	-800				May be preceded by earlier salvoes at +1600, +2400...
0:45	0	Short	+400				Target crossed.
1:30	+400	Over	-200				
2:15	+200	Over	-400	-100	-100	0	Final salvo of bracket.
Rate difference -100 yds/min.							
3:00	-200	Short	+200		-100	-75	Special correction of range but not rate.
3:45	-75	Straddle			-100	-75	Straddling with correct rate.
Rate difference -200 yds/min.							
3:00	-200	Straddle			-100	-75	
3:45	-275	Straddle			-100	-75	
4:30	-350	Over	-200	-100	-200	-75	Normal correction
5:15	-625	Straddle			-200	-150	Straddling with correct rate.
Rate difference -400 yds/min.							
3:00	-200	Over	-400	-100	-200	-75	
3:45	-675	Over	-400	-100	-300	-150	
4:30	-1225	Straddle			-300	-225	
5:15	-1450	Straddle			-300	-225	
6:00	-1675	Over	-200	-100	-400	-225	Normal correction
6:45	-2100	Straddle			-400	-300	Straddling with correct rate.

14. When the rate difference was -100 yds/min., the final salvo of the bracket was OVER, while the rule resulted in the next salvo after the bracket being SHORT. This had to be recognised as a special case; the optimum correction was UP 200 (the normal range correction) but without an accompanying change of rate.

15. When the rate difference was large, the crossing salvo was more likely to straddle than to fall short. If it straddled, the bracket was terminated and the next salvo fired without range or rate correction: but this would fall OVER. A normal correction (DOWN 200, CLOSE 100) would then take too long to find the target

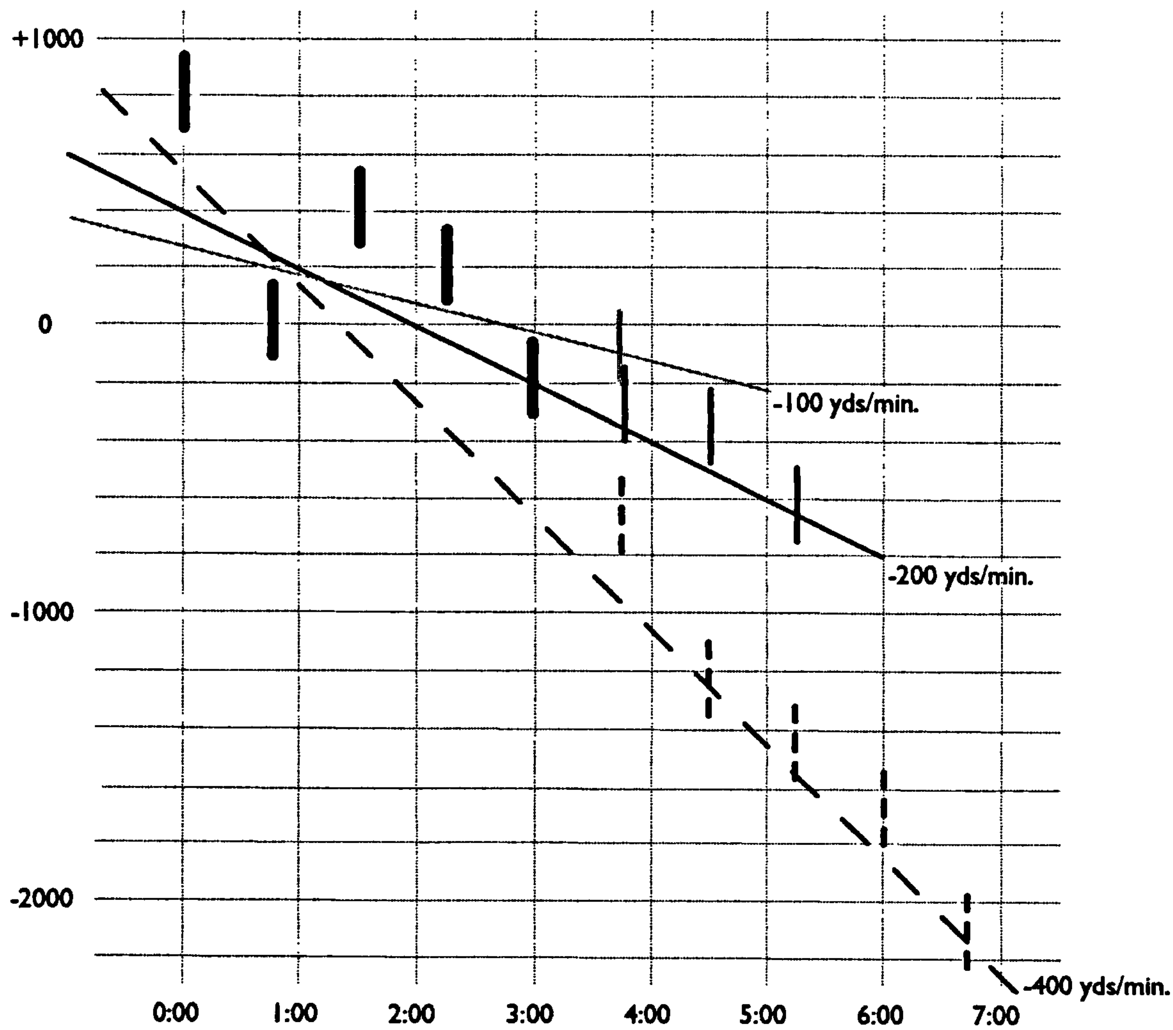


FIG. II.2: RATE SPOTTING CORRECTIONS AFTER A FAILED BRACKET

again. It was better to recognise another special case and apply the correction for a failed bracket (DOWN 400, CLOSE 100).

16. To summarise; if, after crossing the target with a SHORT (OVER) salvo, the remaining salvoes of a bracket all fall OVER (SHORT):

a) correct range and rate by DOWN 400, CLOSE 100 (UP 400, OPEN 100) until the target is straddled

b) if, subsequently, the target is lost again, apply normal corrections of DOWN 200, CLOSE 100 (UP 200, OPEN 100)

c) if the salvo immediately following the final salvo of the bracket is SHORT (OVER), correct the range by UP 200 (DOWN 200) but not the rate.

If the target is crossed by a straddling salvo, and the next salvo falls OVER (SHORT), use corrections of DOWN 400, CLOSE 100 (UP 400, OPEN 100) until the target is straddled again.

17. Thus a few fairly simple rules of thumb could be used to correct even large rate errors by systematic spotting. Unfortunately, their omission from the *Manual of Gunnery* meant that some control officers may have had no clear idea how to recover if their opening brackets made no hits.

APPENDIX III

FIRE CONTROL EQUATIONS

OWN SHIP ALTERS COURSE

1. Angles, courses and speeds are as shown in Fig. 2.11. Own ship S is turning with angular speed $\frac{d\kappa}{dt}$ (the appendices use conventional calculus notation). Assume own speed s remains constant. Enemy course λ and speed e are constant.

2. Obtain virtual course and speed of E relative to S by the vector subtraction shown in Fig. 2.3.

3. Resolve the the virtual speed into components along and across the line of bearing. The speed-along equals the range-rate.

$$\frac{dR}{dt} = a = e\cos\iota - s\cos\beta \qquad \text{(III:1)}$$

4. One knot = one sea-mile per hour i.e. 6080 feet per hour or 33.78 yds/min. Thus, if a, e and s are in knots and $\frac{dR}{dt}$ is required in yds/min.:

$$\frac{dR}{dt} = 33.78\ a \qquad \text{as in 2:2}$$

5. The speed-across x rotates the line of bearing SE relative to the fixed North-pointing reference line. Thus the rate of change of target compass bearing is:

$$\frac{d\chi}{dt} = \frac{x}{R} = \frac{e\sin\iota + s\sin\beta}{R} \qquad \text{(III:2)}$$

where x, e and s are in yds/min., R is in yards and $\frac{d\chi}{dt}$ is in radians/min.

6. If x is in knots and $\frac{d\chi}{dt}$ is required in degrees/min.

$$\frac{d\chi}{dt} = \frac{180}{\pi}.\frac{33.78\,x}{R}$$

$$= 1935.\frac{x}{R} \qquad \text{as in 2:9}$$

7. Since $\beta = \chi - \kappa$:

$$\frac{d\beta}{dt} = \frac{d\chi}{dt} - \frac{d\kappa}{dt} \qquad \text{(III:3)}$$

and when own course is steady i.e. $\frac{d\kappa}{dt} = 0$:

$$\frac{d\beta}{dt} = 1935.\frac{x}{R} \qquad \text{as in 2:4}$$

8. Differentiating equation I:1:

$$\frac{d^2R}{dt^2} = -e \sin \iota \frac{d\iota}{dt} + s \sin \beta \frac{d\beta}{dt} \qquad \text{(III:4)}$$

9. Since $\lambda = \iota + \chi$ and λ is constant, $\frac{d\iota}{dt} = -\frac{d\chi}{dt} = -\frac{x}{R}$

Substituting in III:4 for $\frac{d\iota}{dt}$ and for $\frac{d\beta}{dt}$ from III:3 and III:2:

$$\frac{d^2R}{dt^2} = e \sin \iota.\frac{x}{R} + s \sin \beta.\frac{x}{R} - s \sin \beta.\frac{d\kappa}{dt}$$

$$\frac{d^2R}{dt^2} = \frac{x^2}{R} - s \sin \beta.\frac{d\kappa}{dt} \qquad \text{(III:5)}$$

where x and s are in yds/min., R is in yards, $\frac{d\kappa}{dt}$ is in radians/min.

and $\frac{d^2R}{dt^2}$ is in yds/min/min.

10. If x and s are in knots and $\frac{d\kappa}{dt}$ is in degrees/min.

$$\frac{d^2R}{dt^2} = \frac{(33.78\,x)^2}{R} - 33.78 \,.\, s \sin \beta.\frac{\pi}{180}.\frac{d\kappa}{dt}$$

$$= 1141.\frac{x^2}{R} - 0.5895 \,.\, s \sin \beta.\ \frac{d\kappa}{dt} \qquad \text{(III:6)}$$

and when own course is steady:

$$\frac{d^2R}{dt^2} = \dot{a} = 1141.\frac{x^2}{R} \qquad \text{as in 2:6}$$

11. The second of the right hand terms in III:6 is a measure of the curvature of the range-time graph due to the change of course. Halfway through *Lion's* turn at 4.18-19, s remained 24 knots, β was -97° and $\frac{d\kappa}{dt}$ +20°/min;[1] thus this term evaluates to 281 yds/min/min. Notice how much bigger this term is compared with the values calculated for the first term in Chapter 2. In fact, even when x is at its maximum, the second term is still important. Take the case of the two 25-knot ships 16,000 yards abeam on opposite courses: but now with the firing ship also

[1] 'Record of events during action of May 31st compiled from records kept in Control Position and Transmitting Station. H.M.S. Lion' in BTY 6/6, NMM.

altering course at 20°/min., both inwards and outwards. Then:

$$\frac{d^2R}{dt^2} = 178 \mp 295 \text{ yds/min/min.}$$

Even if the range is halved to 8,000 yards, which doubles the first term, the second term remains significant.

From ranges of values for β and ι inserted in the fire control equations, III:6 establishes that a turn by the firing ship caused a rapid change in range-rate in all tactical circumstances except those in which the enemy was almost dead ahead or astern (β close to 0° or 180°). Even then, gunnery remained difficult because the rate of change of deflection due to course alterations was at a maximum (see III:10 below). Thus in *all* tactical situations, course changes induced rapid change in range-rate, deflection or, usually, both. In contrast, rapid changes due to high speed-across occurred only in limited (and rather uncommon) circumstances.

12. To obtain $\frac{d^2\chi}{dt^2}$, substitute as above after differentiating:

$$R.\frac{d\chi}{dt} = e\sin\iota + s\sin\beta$$

$$R.\frac{d^2\chi}{dt^2} + \frac{dR}{dt}.\frac{d\chi}{dt} = e\cos\iota.\frac{d\iota}{dt} + s\cos\beta.\frac{d\beta}{dt}$$

$$= -e\cos\iota.\frac{d\chi}{dt} + s\cos\beta.\frac{d\chi}{dt} - s\cos\beta.\frac{d\kappa}{dt}$$

$$\frac{d^2\chi}{dt^2} = -\frac{2ax}{R^2} - \frac{s\cos\beta}{R}.\frac{d\kappa}{dt} \qquad \text{(III:7)}$$

where R is in yards, a, x and s are in yds/min., $\frac{d\kappa}{dt}$ is in radians/min.

and $\frac{d^2\chi}{dt^2}$ is in radians/min/min. When speeds are in knots and angles in degrees:

$$\frac{d^2\chi}{dt^2} = \left(\frac{180}{\pi}\right)\left(-\frac{2\,.\,33.78^2\,.\,ax}{R^2} - \frac{33.78\,.\,s\cos\beta}{R}.\frac{d\kappa}{dt}.\frac{\pi}{180}\right)$$

$$\frac{d^2\chi}{dt^2} = -\frac{130759\,.\,ax}{R^2} - \frac{33.78\,.\,s\cos\beta}{R}.\frac{d\kappa}{dt} \qquad \text{(III:8)}$$

13. From I:1,

$$\frac{da}{dt} = \frac{d^2R}{dt^2}$$

Differentiating the expression for speed-across x (implicit in I:2) by analogy with paragraphs 8 and 9:

$$\frac{dx}{dt} = -\frac{ax}{R} - s\cos\beta.\frac{d\kappa}{dt} \qquad \text{(III:9)}$$

To obtain $\frac{dx}{dt}$ in knots/min. when a, x and s are in knots and $\frac{d\kappa}{dt}$ is in degrees/min.:

$$33.78.\frac{dx}{dt} = -\frac{33.78^2 \,.\, ax}{R} - 33.78 \,.\, s\cos\beta.\frac{\pi}{180}.\frac{d\kappa}{dt}$$

$$\frac{dx}{dt} = -\frac{33.78\,ax}{R} - \frac{s\cos\beta}{57.30}.\frac{d\kappa}{dt} \qquad \text{(III:10)}$$

14. When own course is steady, equations III:10 and III:8 reduce to equations 2:7 and 2:8, respectively.

ENEMY ALTERS COURSE

1. If own course remains steady but enemy alters course, turning at $\frac{d\lambda}{dt}$, similar equations for the rate of change of rate can be derived using the same methods.
2. The equations analogous to I:5 and I:7 are:

$$\frac{d^2R}{dt^2} = \frac{x^2}{R} - e\sin\iota.\frac{d\lambda}{dt} \qquad \text{(III:11)}$$

$$\frac{d^2\chi}{dt^2} = -\frac{2ax}{R^2} + \frac{e\cos\iota}{R}.\frac{d\lambda}{dt} \qquad \text{(III:12)}$$

APPENDIX IV

STRAIGHT-COURSE PLOT

1. This appendix chiefly concerns the type of straight-course plot which uses a directional reference (in practice a gyroscope) which maintains its direction even after a turn by own ship.
2. Normally, the directional reference is set at first to point along the initial mean course line. The plot of enemy course and speed will then show the true course and speed until own ship alters course. After the turn, the plotted enemy course and speed is no longer true, but it can still be used to obtain a correct virtual course (and hence range-rate and deflection): see Chapter 2.
3. After the turn, enemy bearings are measured relative to the directional reference, not to the mean new course. It will be sufficient to prove that, if a straight-course plot is made relative to *any* arbitrarily-set directional reference, a correct virtual course can be obtained.
4. ST represents a portion of the true course of own ship; its length is proportional to the distance travelled by own ship. EF represents the corresponding portion of the enemy course. Thus SE and TF are lines of bearing and their lengths are proportional to range.
5. Angles TSE and UTF are equal to the target bearing angles, β.
6. ST′ lies in the direction indicated by the gyroscopic reference. When making the straight-course plot, own ship's course is drawn as a straight line, the length being proportional to the distance travelled. Let ST′ also represent this straight line.

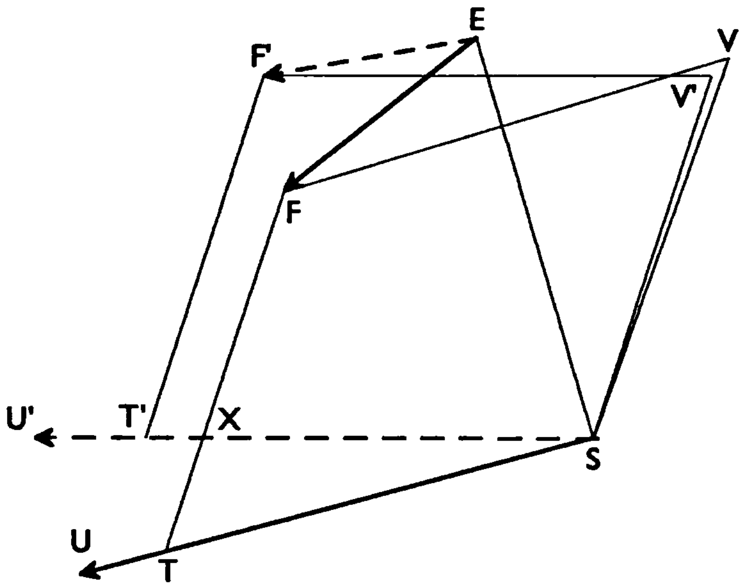


Fig. IV.I

Thus, in length:

$$ST = ST'$$

while angle TST' is the difference between own course and the directional reference, a.

7. In making the straight-line plot, the enemy course is plotted relative to own-course line ST'; the ranges are the same as those used for the true-course plot, while target bearings β' are measured relative to the directional reference. Thus, in length:

$$T'F' = TF$$

From triangle XST:

$$\angle T'XF = \angle UTX - \angle TSX = \beta - a = \beta'$$

Since $\angle U'T'F'$ is also equal to β', TF and $T'F'$ are parallel. In vector notation:

$$\overline{T'F'} = \overline{TF} \qquad \text{(IV:1)}$$

8. SE represents the line-of-bearing for both the true-course and straight-line plots.

9. EV represents the true virtual course of the target. It is found by the triangle of velocities EFV which subtracts own speed from enemy speed. Thus FV is parallel to TS, FVST is a parallelogram and:

$$\overline{SV} = \overline{TF}$$

10. EV′ is the virtual course obtainable from the straight-course plot by the vector-subtraction of the plotted own-course ST′ from enemy-course EF′. As above, F′V′ST′ is a parallelogram; therefore:

$$\overline{SV'} = \overline{T'F'}$$

From IV:1:

$$\overline{SV'} = \overline{SV} \qquad \text{and, therefore} \qquad \overline{EV'} = \overline{EV}$$

Thus both the true-course and the straight-course plots give the same virtual course and speed.

11. N.B. This result is obtained without relying on the initial assumption that:

$$ST = ST'$$

Thus the correct virtual speed is obtained even if the straight-course plot is made with an apparent speed different from the true value of own speed. The limiting case is that of the virtual course plot, on which own apparent speed is zero.

These principles were fully understood by Pollen and Isherwood at the time of the *Ariadne* trial. Pollen wrote of one day's plotting:

> We started the record with the paper at 20 knots, and subsequently, to open out the course, reduced the speed of the paper to 10 knots. With our present experience, under similar conditions, we should probably prefer to keep the paper altogether stationary, so as to put the whole of our speed on to the target, and make the record clearer.[1]

[1] 'Notes on charts, made before Christmas sent to Admiral Wilson' p.2 in *Notes, Correspondence, Etc. on the Pollen A.C. System installed and tried in H.M.S. Ariadne, December 1907 - January 1908* in DRAX 3/1, CC.

APPENDIX V

ERRORS IN ENEMY SPEED

1. As explained in Chapter 2, a single rangefinder range could have a random error of up to ±400 yards at long ranges. In rough conditions or after a change of course, bearing errors could amount to several degrees, making the speed errors much too high. However, assume a course plot made in favourable conditions on a steady course. Thus the main causes of bearing errors were bearing transmission ($\pm^1/_8°$), observational errors, gyro-compass wander and hunting, either by the gyro-stabilised Argo rangefinder mounting or by the servo which followed the gyro-compass receiver and corrected keel-line bearings for yaw (see Chapter 4 for the Argo Plotter Mark IV). Apart from transmission errors, no reliable numbers are available; however, it is very unlikely that, in total, the random bearing errors were smaller than $\pm½°$ and this figure is used in the following analysis.

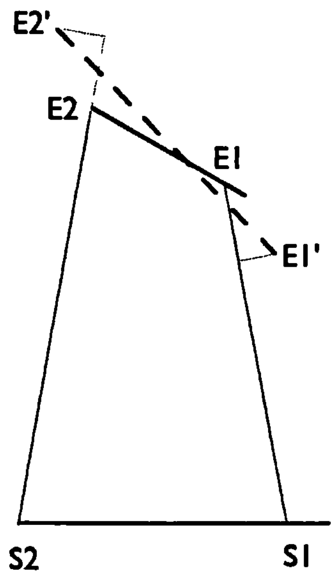


FIG. V.1

2. Fig. V.1 shows a portion of a true or straight course plot. S1 S2 represents own course and E1 E2 represents the enemy course that would be plotted if there were no range and bearing errors. These errors result in plotted points E1′, E2′ which are displaced from the correct position. Range errors result in displacements along the line-of-bearing, bearing errors in displacements perpendicular to the line-of-bearing.

3. The displacements drawn in Fig. V.1 result in the maximum positive error in the apparent enemy speed for the courses and bearings shown.

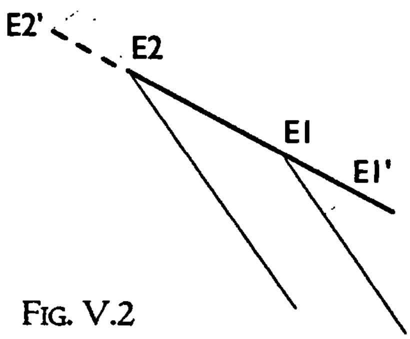


FIG. V.2

4. The worst possible error in enemy speed is obtained if the displacements E1 E1′ and E2 E2′ both lie along the enemy's true course E1 E2, as shown in Fig.V.2.

5. The range displacement is a maximum of 400 yards.

6. If the bearing error is ½°, the resultant lateral displacement when the range is 16,000 yards is 140 yards. Therefore the total displacement of each plotted point along the true course line is 424 yards.

7. If the enemy is making 25 knots, the true distance covered in 2 minutes is 1689 yards. Thus the worst case speed error obtained from two points separated in time by 2 minutes is $\frac{2 \times 424 \times 25}{1689}$ knots i.e. 12.6 knots too high.

8. Large speed errors (approximately 10-12 knots) result when the displacements of the two points due to the dominant range errors, are:
   a) close to the maximum error value and
   b) in opposite directions; on average, this second condition arises with 50% of selected pairs of points.

9. In reality, the errors of range or bearing are distributed symmetrically about zero according to a statistical distribution, probably a normal distribution.

10. Since errors are equally likely to be positive or negative, if sufficient pairs of points are measured:
   a) the speed errors will be distributed symmetrically about zero
   b) the errors will average out and a good approximation to the enemy speed will be obtained.

However, due to the spread of speed values, this averaging effect will only be obtained after measurements on many pairs of points. Little confidence can be placed in the first few speeds obtained. It is necessary to wait until the mean is clearly converging towards a steady value.

11. Even after plotting for 2 minutes, the worst case speed error is still very high. Since about 3 to 4 ranges could be taken with a single rangefinder, a mean course line might begin to be perceptible after this time, while a first speed value could be calculated from the first and last ranges obtained. However, it would then be necessary to continue plotting for at least another 2 minutes. This would allow 6-8 speeds to be measured from pairs of points each separated by about 2 minutes. After 4 minutes, there might be some hope that the mean speed was converging, while a better estimate of enemy course could also be made.

12. Alternatively, it might be better to wait longer before first measuring the speed; by waiting for 3 rather than 2 minutes, the worst case speed error would be reduced to about 8 knots. However, it would still be necessary to measure further values to obtain a converging mean speed. Probably, the error after 4 minutes would not be much different from the preceding case.

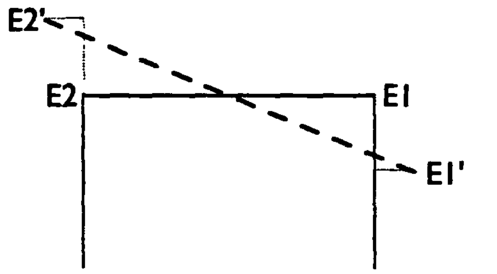


FIG. V.3

13. The calculation of worst case error assumed a constant bearing angle, which resulted in the total displacement, due to both range and bearing errors, falling along the enemy course line. In practice, this course line could be at any angle to the lines of bearing. The worst case error is at a minimum when the enemy course is at right angles to the lines of bearings. If E1 E2 is 1689 yards:

$$E1'\,E2' = \sqrt{(1689+280)^2+800^2} = 2125 \text{ yards.}$$

Thus the speed error is almost halved, to $\frac{2125-1689}{1689} \times 50 = 6.45$ knots.

APPENDIX VI

RATE PLOTTING ERRORS

1. The maximum speed-across is found when two ships pass on opposite courses, beam-to-beam.
2. Consider the case of two 25-knot ships passing at 16,000 yards. Rate plotting begins one minute before they pass (when the ships are at S0, E0) and the first attempt to measure a range-rate is made one minute after they pass (ships at S2, E2).
3. Fig. VI.1 shows a true-course and a virtual-course representation of the positions of the two ships. In the two minutes, each ship travels 1689 (2 x 25 x 33.78) yards, while the target bearing increases by 12.05°.

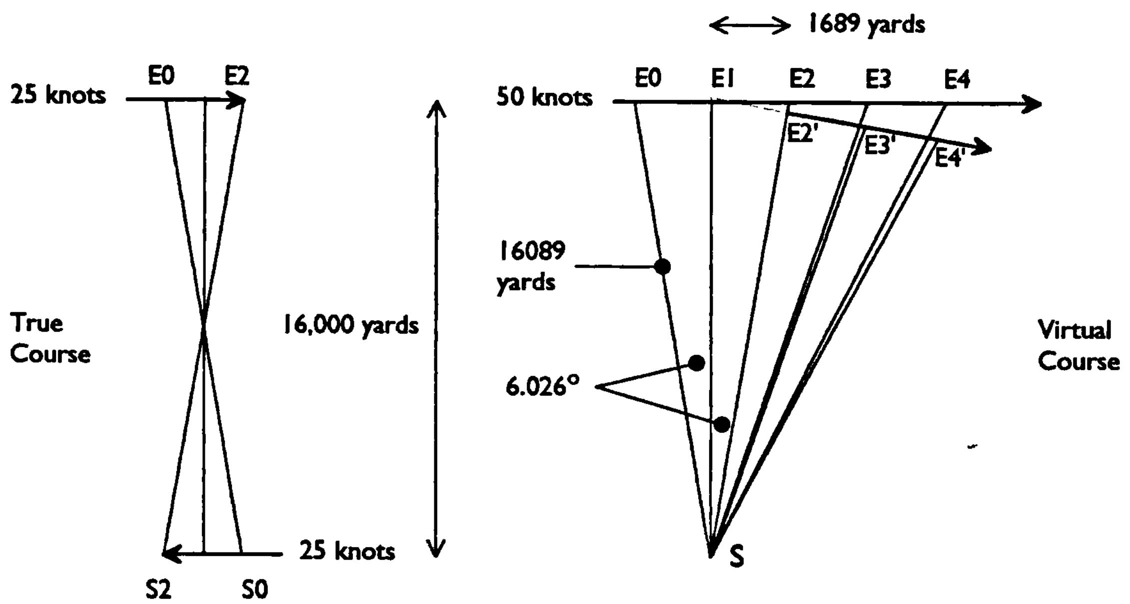


FIG. VI.1

4. From the right triangle E0 E1 S, the actual range when plotting begins is 16,089 yards; it then falls to a minimum of 16,000 yards.

5. Due to the rapid change in range-rate, the real slope of the underlying curve of the range-plot changes from negative to positive, being momentarily zero as the ships pass. Assume, however, that the scatter of ranges entirely obscures the curvature. Thus, after plotting for two minutes, the mean line through the range plot will appear, on average, to have a slope of 0 yds/min., whereas:

$$\text{Actual range-rate at E2} = 50 \times 33.78 \times \sin\left(\tan^{-1}\frac{1689}{16,000}\right)$$

$$= 177 \text{ yds/min.}$$

In other words, the range-rate error due to the failure to recognise the curvature is -177 yds/min.

6. After 2 minutes' plotting, assume that the average apparent range on the plot is half way between the actual minimum and maximum ranges i.e. the apparent mean range S E2′ is 16,044 yards. Thus the range error after 2 minutes plotting is -45 yards.

7. Assume that, after 2 minutes, a Dumaresq is set by a cross-cut with the rates from the plot. The virtual course must be at right angles to the line-of-bearing S E2′ E2 to give a speed-along of zero; the virtual speed must be such as to give a change in bearing of 6.026° in the previous minute. Assume also that the Dumaresq is part of a range-and-bearing clock which is started after 2 minutes. Then, after one more minute, the bearing will change by a further 6.026°. Thus, from right triangle S E2′ E3′, the travel along the apparent virtual course is 1693.6 yards and the predicted range is 16,133 yards. However, from right triangle S E1 E3, the true range is 16,353 yards; thus the range error increases to -220 yards.

8. Similarly, true and predicted ranges can be calculated for 4 and 5 minutes after plotting began. The errors in ranges, and average errors in range-rate in each minute, are tabulated below.

Time (mins.)	True Range (yards)	Clock Range (yards)	Range Error (yards)	Rate Error (yds/min.)
2	16,089	16,044	-45	-177
3	16,353	16,133	-220	-175
4	16,783	16,398	-385	-165
5	17,368	16,829	-539	-154

9. Thus the range error increases at a rate which is close to the initial rate error; though the rate actually reduces somewhat. Probably after 4 minutes, certainly after 5, the divergence between the observed and predicted ranges would have been apparent, despite the uncertainty in the ranges of ±300-400 yards (see Chapter 2). Range and rate could then be corrected as when spotting for rate; for example, two corrections of UP 200, OPEN 100 would eliminate the errors accumulated after 4 minutes.

Appendices to Chapter 3

APPENDIX VII

THE DUMARESQ MARK VI

1. The scales of the Mark VI Dumaresq are illustrated in Fig. VII.1 overleaf. The angular settings on the instrument correspond to the courses and angles shown in the lower diagram.
2. The instrument had two compass rings, graduated in degrees of bearing from 0° to 360°. The two rings were connected by gears so that they rotated together. When correctly set, the zeros of the scales pointed North.
3. The 'own compass ring' rotated outside the circumference of the dial (the dial carried the large arrow which was kept pointing at the target). The 'enemy compass ring' was centred on the sliding pivot of the enemy bar (the enemy bar being represented by the smaller arrow).[1]
4. To set the enemy course, the enemy bar could be turned relative to the enemy compass ring. Once so set, the enemy bar rotated with the enemy compass ring.
5. The two compass rings could be rotated rapidly by pushing on the own compass ring. For finer, but slower, adjustment, a small hand-wheel, driving the rings through a worm, could be engaged.
6. As the rings rotated, the dial rotated with them. However, the dial could also be rotated independently.[2]
7. The outer edge of the dial was graduated in degrees of target bearing between 0° and 180° to port and to starboard.[3]

[1] For the names of the two compass rings, see G K B Elphinstone, 'Dumaresq Instruments Designs and Patents. Notes as to History' 31 January 1916 in 'Fire Control Apparatus. Various Patents', ADM 1/8464/181.

[2] Admiralty, Gunnery Branch, *Manual of Gunnery (Volume III) for His Majesty's Fleet 1915*, pp. 172-3, AL.

[3] F C Dreyer and C V Usborne, *Pollen Aim Corrector System. Part I. Technical History and Technical Comparison with Commander F.C.Dreyer's Fire Control System*, 1913, Fig. 6, P.1024, AL.

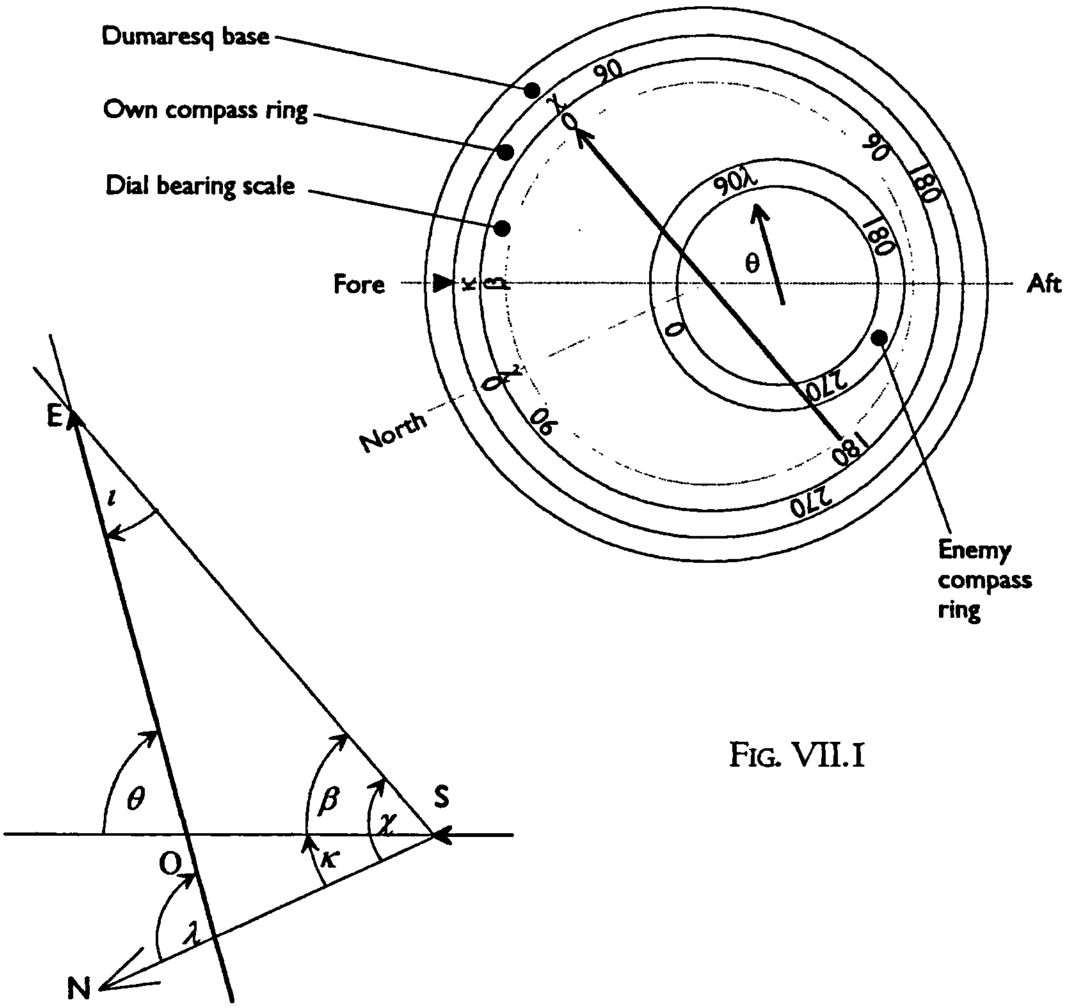


FIG. VII.I

8. Against the pointer located at the fore end of the fore-and-aft bar:
   the dial bearing scale indicated target bearing angle, β
   the own compass ring indicated own course, κ

9. To set the instrument initially, the compass rings were rotated until the own compass ring indicated own ship's compass course. The enemy bar was set for own and enemy speeds and for enemy course. Finally, the dial plate alone was rotated until the arrow pointed at the target. The range-rate and deflection could then be read off the dial plate as indicated by the enemy bar. Provided the arrow was kept pointing at the target, the enemy bar would continue to indicate range-rate and deflection even as they changed as the target bearing changed.

10. If own ship altered course, the operator used the hand-wheel to rotate the two compass rings and, with them, the dial and the enemy bar: thereby keeping the

arrow on the dial plate pointing at the target. At the end of the turn, the target bearing β was therefore still correct but, as will be shown below, own course κ and the angle between courses θ were only maintained approximately.

11. If a gyro-compass repeater was adjacent to the Mark VI Dumaresq, the compass courses indicated by the two instruments could have been compared and the hand-wheel used to correct the Dumaresq's course readings. This would also correct the angle between courses. It would also move the dial-arrow off the target but the dial plate could then be immediately rotated on its own to point the arrow once more at the target. However, this technique was not mentioned in the *Manual of Gunnery 1915*.

12. Let the actual change in own compass course through the turn be $\Delta\kappa$: and let the change indicated by the Dumaresq be $\Delta\kappa'$. Let the actual and indicated change in target bearing be $\Delta\beta$: and let $\Delta\theta$ and $\Delta\theta'$ be the true and indicated change in the angle between courses.

13. When the two rings, the dial and the enemy bar were rotated such that β is increased, θ was increased and κ was decreased by the same amount i.e.

$$\Delta\beta = \Delta\theta' = -\Delta\kappa' \qquad \text{(VII:1)}$$

14. From equation III:2, the change in target compass bearing $\Delta\chi$ is:

$$\Delta\chi = \int \frac{x(t)}{R(t)}dt \qquad \text{(VII:2)}$$

But, since $\chi = \kappa + \beta$:

$$\Delta\chi = \Delta\kappa + \Delta\beta = \Delta\kappa - \Delta\kappa' \qquad \text{from VII:1}$$

Thus the error in own compass course indicated after the turn:

$$\Delta\kappa' - \Delta\kappa = -\Delta\chi$$

In other words, the error is equal in magnitude but opposite in sign to the change in target compass bearing. As equation VII:2 shows, this error is most significant when the speed-across x is high and the range R low.

15. Since $\theta + \kappa = \lambda$, where λ is the enemy compass course, which is assumed to be constant:

$$\Delta\theta = -\Delta\kappa$$

so the error in enemy course is :

$$\Delta\theta' - \Delta\theta = \Delta\chi$$

16. The error in θ can also be explained by the fact that, through the turn, the angle between the enemy bar and the bearing arrow does not change i.e. that the inclination angle set on the Dumaresq does not change. In fact, because:

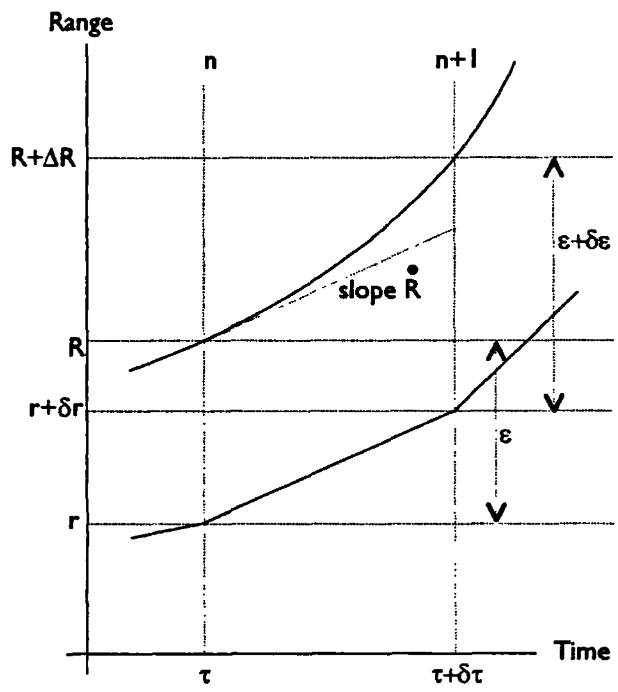
$$\iota + \chi = \lambda$$

$$\Delta\iota = -\Delta\chi$$

Like the Mark VI Dumaresq, the Argo Clock Mark III also kept the angle between the enemy bar and the line of bearing constant through a turn, and therefore relied on the same approximation.

APPENDIX VIII

Rate Transfer Error



1. The true target range R follows a smooth hyperbolic curve; the tangent to the curve has a slope equal to the range-rate $\dot{R}$
2. The rate is transferred in steps to the range clock each time the pointer of the Dumaresq crosses a rate-line on the dial; the lines are spaced at intervals of 100 yds/min.
3. Between rate alterations, the range clock runs at a constant rate. Thus a graph of the clock range r consists of a series of straight-line segments. The slope of each segment equals the range-rate $\dot{R}$ at the time of transfer, τ.
4. Let the time of the next rate transfer be $\tau + \delta\tau$. At that time, let the true-range be $R + \Delta R$ and the clock-range $r + \delta r$. Let the errors in the clock-range due to its lag behind the true-range be ε at τ and $\varepsilon + \delta\varepsilon$ at $\tau + \delta\tau$. Then:

$$\delta\varepsilon = \delta r - \Delta R \qquad \text{(VIII:1)}$$

where $\delta r = \dot{R}\,\delta\tau$ (VIII:2)

5. Using the form of the hyperbolic equation given in Fig. 2.6:

$$R^2 = R_0^2 + v^2t^2 \qquad \text{(VIII:3)}$$

Differentiating:

$$2R.\frac{dR}{dt} = 2v^2t \qquad \text{i.e. } \dot{R} = \frac{v^2t}{R} \qquad \text{(VIII:4)}$$

Note that $R = R_0$ and $\dot{R} = 0$ when $t = 0$.

6. Let the size of the rate-steps be ρ. In order to calculate how the clock-error ε increases with time, assume that:

a) the clock is started at $t = 0$ with zero rate and zero error

b) the first rate is transferred when $\dot{R} = \rho$

c) the nth rate is transferred when $\dot{R} = n\rho$ at time $t = \tau$.

7. Thus, from VIII:4

$$n\rho = \frac{v^2\tau}{R} \qquad \text{(VIII:5)}$$

Squaring and substituting for R from VIII:3

$$n^2\rho^2 = \frac{v^4\tau^2}{R_0^2 + v^2\tau^2}$$

$$n^2\rho^2R_0^2 + n^2\rho^2v^2\tau^2 = v^4\tau^2$$

$$v^2\tau^2 = \frac{n^2\rho^2R_0^2}{v^2 - n^2\rho^2}$$

Substituting back into VIII:3

$$R^2 = R_0^2\left(1 + \frac{n^2\rho^2}{v^2 - n^2\rho^2}\right) = R_0^2\left(\frac{v^2}{v^2 - n^2\rho^2}\right)$$

$$R = \frac{R_0}{\sqrt{1 - \left(\frac{n\rho}{v}\right)^2}} \qquad \text{(VIII:6)}$$

8. From VIII:5

$$\tau = \frac{n\rho R}{v^2} \qquad \text{(VIII:7)}$$

9. Equations VIII:2, 6 and 7 are in convenient forms to calculate R, r and ε. The following table is for the case of high curvature and lag, with:

$R_0 = 8{,}000$ yards

$\rho = 100$ yds/min.

$v = 1{,}689$ yds/min. i.e. two 25 knot ships passing on opposite courses.

n	R yards	τ mins.	$\delta\tau$ mins.	$\dot{R}$ when $t=\tau$ yds/min.	$\dot{R}\delta\tau$ yards	r yards	ε yards	$\frac{\delta\varepsilon}{\delta\tau}$ yds/min.
0	8,000	0	0.2809	0	0	8,000	0	
1	8,014.06	0.2809	0.2839	100	28.39	8,000	-14.06	-50
2	8,056.68	0.5648	0.2901	200	58.02	8,028.39	-28.29	-50
3	8,129.26	0.8549	0.2997	300	89.91	8,086.41	-42.85	-50
4	8,234.25	1.1546	0.3134	400	125.36	8,176.32	-57.93	-50
5	8,375.4	1.468	0.332	500	166	8,301.68	-73.72	-50
6	8,558.2	1.8	0.357	600	214.2	8,467.68	-90.52	-51
7	8,790.49	2.157	0.3903	700	273.21	8,681.88	-108.61	-51
8	9,083.56	2.5473	0.4353	800	348.24	8,955.09	-128.47	-51
9	9,453.99	2.9826	0.4972	900	447.48	9,303.33	-150.66	-51
10	9,926.92	3.4798				9,750.81	-176.11	-51

10. The last column suggests that the clock error i.e. the difference between the clock and true ranges, increases in magnitude by a rate which is essentially constant. The following sections develop an expression for $\frac{\delta\varepsilon}{\delta\tau}$.

11. From VIII:7

$$\tau+\delta\tau=\frac{\rho}{v^2}(n+1)(R+\Delta R)$$

Subtract VIII:7 to obtain:

$$\delta\tau=\frac{\rho}{v^2}[R+(n+1)\Delta R] \qquad \text{(VIII:8)}$$

12. From VIII:3

$$(R+\Delta R)^2=R_0{}^2+v^2(\tau+\delta\tau)^2$$

$$R^2+2R\,\Delta R+\Delta R^2=R_0{}^2+v^2\tau^2+2v^2\tau\,\delta\tau+v^2\delta\tau^2$$

Subtracting VIII:3

$$2R\,\Delta R+\Delta R^2=2v^2\tau\,\delta\tau+v^2\delta\tau^2$$

$$\Delta R(2R+\Delta R)=v^2\delta\tau(2\tau+\delta\tau)$$

Substituting for τ from VIII:7 and $\delta\tau$ from VIII:8

$$\Delta R(2R+\Delta R)=v^2\delta\tau\left[2\frac{\rho}{v^2}nR+\frac{\rho}{v^2}R+\frac{\rho}{v^2}(n+1)\Delta R\right]$$

$$=\delta\tau[(2n+1)\rho R+(n+1)\rho\,\Delta R]$$

Divide through by $2R\,\delta\tau$.

$$\frac{\Delta R}{\delta\tau}\left(1+\frac{\Delta R}{2R}\right)=\left(n+\frac{1}{2}\right)\rho+\frac{(n+1)\rho\,\Delta R}{2R}$$

Multiply through by $\left(1-\frac{\Delta R}{2R}\right)$

$$\frac{\Delta R}{\delta \tau}\left(1-\frac{\Delta R^2}{4R^2}\right)=\left(n+\frac{1}{2}\right)\rho-\frac{\left(n+\frac{1}{2}\right)\rho\,\Delta R}{2R}+\frac{(n+1)\rho\,\Delta R}{2R}-\frac{(n+1)\rho\,\Delta R^2}{4R^2}$$

$$=\left(n+\frac{1}{2}\right)\rho+\frac{\rho\,\Delta R}{4R}-\frac{(n+1)\rho\,\Delta R^2}{4R^2}$$

From the table of calculated values, when n = 9, R = 9,454 yards and ΔR = 473 yards; thus $\frac{\Delta R^2}{4R^2}$ = 0.0006, so these terms are negligible.

$$\frac{\Delta R}{\delta \tau}\simeq\left(n+\frac{1}{2}\right)\rho+\frac{\rho\,\Delta R}{4R} \qquad \text{(VIII:9)}$$

13. From VIII:1 and VIII:2 and since $\frac{\delta r}{\delta \tau}=\dot{R}=n\rho$:

$$\frac{\delta \varepsilon}{\delta \tau}=\frac{\delta r}{\delta \tau}-\frac{\Delta R}{\delta \tau}$$

$$\simeq n\rho-\left(n+\frac{1}{2}\right)\rho-\frac{\rho\,\Delta R}{4R}$$

$$\simeq-\frac{\rho}{2}\left(1+\frac{\Delta R}{2R}\right) \qquad \text{(VIII:10)}$$

When n = 9, the calculated values from the table give a value for the $\frac{\Delta R}{2R}$ term of 0.025; thus the expression gives the same value for $\frac{\delta \varepsilon}{\delta \tau}$ as that obtained by calculation. However, for most purposes, to a good approximation:

$$\frac{\delta \varepsilon}{\delta \tau}\simeq-\frac{\rho}{2} \qquad \text{(VIII:11)}$$

i.e. the clock-range lags behind the true-range by an amount which increases in magnitude at a steady rate equal to half the size of the rate steps.

14. This analysis applies mainly to the curved part of the range-time hyperbola. As the curve approaches the asymptotes, the times between the rate steps become longer. The value of n for the final rate step is determined from VIII:6, since:

$$\frac{n\rho}{v}<1$$

Thus, for the values of ρ and v assumed earlier, $n \leqslant 16$

If equation VIII:6 is used to calculate R for n = 15 and 16, $\frac{\Delta R}{2R}$ = 0.22. Thus the approximation for $\frac{\delta \varepsilon}{\delta \tau}$ holds reasonably well even out to these theoretical limits. In practice, of course, the true rate would have been essentially constant: other sources of range and rate errors would have been predominant: and both would have been corrected together using the rate spotting procedures described in Chapter 2.

15. The preceding equations have been derived by considering the part of the range-time hyperbola where the range is increasing i.e. n, and ΔR are all positive. All these variables are negative when the range is decreasing. However, equations VIII:10 and VIII:11 still hold: although, if numeric values for ΔR are inserted in VIII:10, they will be negative. Thus, when the rate is negative, the error increases in magnitude by slightly *less* than half the size of the rate steps. This can be verified by recalculating the figures in the table. If the clock is started 3.4798 minutes before the ships pass beam-to-beam, by the time they do so the accumulated error will be 171.87 yards. As the table shows, a further 176.11 yards will accumulate by the time the range returns to its starting value after almost 7 minutes.

16. A total error of almost 350 yards may seem serious, but it could only accumulate if the clock remained uncorrected by rangefinding or spotting. This circumstance would only arise if the target became and remained invisible as soon as the clock was started, but then the Dumaresq could not keep the range-rate to set on the clock.

APPENDIX IX

THE VICKERS CLOCK

DEVELOPMENT

By mid-1907, two or more Vickers clocks had been supplied to ships with electrical fire control 'according to the description of guns on board', a policy reiterated by Bacon in 1909.[1] In 1908, the addition of a second, outer gun range dial for the Vickers clock was being considered, but this was not adopted.[2] However, for use in local turret control, the clock was later fitted with a second red gun-range pointer mounted frictionally on the same axis as the original black pointer, the latter then indicating rangefinder range (this dual-pointer clock had already been introduced by 1913).[3]

Apart from the red pointer, the Vickers clock had by 1909 reached its final form. From the start, the production model differed from Percy Scott's proposal of late 1903 in providing a much greater span of ranges. The graduated rim 'is divided into 4,000 yards but the graduations are numbered through windows in the face so that 3 ranges are available, 2,000-6,000 6,000-10,000 and 10,000 to 14,000 yards'. The numbers were in 100 yard steps while the divisions on the graduation ring were separated by 25 yards.[4] Originally, the rim was revolved by hand but in 1908 a handle was added to make it easier to set spotting corrections, one turn of the handle being equivalent to 100 yards.[5]

[1] *Paper prepared by the Director of Naval Ordnance and Torpedoes for the Information of his Successor, July 1907*, p.20 and November 1909, p.16.
[2] Admiralty, Gunnery Branch, *Fire Control*, 1908, pp. 50-52 in ADM 1/8010 and T.173/91 Part I, PRO.
[3] *Home Fleet General Orders*, '39. Local Control', 15 September 1913, p.3 in DRAX 1/9, CC.
[4] Admiralty, Gunnery Branch, *Addenda (1909) to Gunnery Manual Vols. I (Part I) and Part III*, November 1909, p.54 and Plate XXVII, AL. The plate shows the clock with figures running from 2,000 to 6,000 yards inclusive: in which case the rim was divided into 4,100 yards. The clock could still have indicated the range continuously if the numbers behind the first window, for example, were 2,000, 6,100 and 10,200 yards. Alternatively, the illustrator may have drawn one too many windows: in which the ranges would have been 2,000 to 5,900, 6,000 to 9,900, etc..
[5] Admiralty, Gunnery Branch, *Half Yearly Summary of Progress in Gunnery, July 1908*, p.8, Ja238, AL.

In the first models, the rate drum was calibrated in knots but also, like the contemporary Dumaresq, in seconds-per-50 yards 'so that, in case of breakdown of the clock a stop-watch can be used'.[6] In 1909, after the introduction of rate-plotting, it was decided to change the rate graduations of Dumaresqs, clocks and rate instruments to yards-per-minute.[7] The abolition of the old rate units, which were only appropriate when keeping the range with a stop-watch, may also have marked an increasing confidence in the reliability of the Vickers clock as the principal range keeper. However, the initial caution about the reliability of the Vickers clock does seem to have been justified. Extensive design changes were needed to make it run accurately and it remained a delicate instrument which required careful handling and a shock-absorbing india-rubber base. To understand the difficulties experienced, it is necessary to look at its internal mechanisms.

When Scott and Vickers proposed and patented the clock in 1903-04,[8] variable-speed drives of many different forms were known and used in a variety of mechanical applications.[9] Such a drive was therefore a natural choice as the basis for a device which, when set with range rate, was required to indicate range. Although a double-cone drive is mentioned in the patent, a basic variable-speed drive of the disc-and-roller pattern was actually used, with the large disc making one rotation in approximately two minutes. The small roller was arranged to slide on a slotted shaft mounted across the diameter of the disc, its position being determined by a carriage moving on two threaded rods; these rods were geared to the rate drum. Thus by rotating the rate handle, the wheel could be positioned anywhere on the diameter of the disc. Springs held the wheel in firm frictional contact with the disc; a pinion at one end of the wheel shaft engaged with a large crown gear which pivoted at the centre of the clock face and carried the range pointer itself.

[6] *SPG* (*op. cit.*) *July 1906*, pp.24.
[7] Admiralty, Gunnery Branch, *Information regarding Fire Control, Range Finding and Plotting*, 1909, pp.17 and 31 in Ja010, AL.
[8] Patent 9461 of 1904, applied for (by Trevor Dawson and James Horne of Vickers Sons & Maxim) 25 April 1914, complete specification 24 February 1905.
[9] A survey of *Patents for Inventions, Abridgements of Specifications* for the periods 1901-4, 1905-8 and 1909-15 shows that patents were taken out every year for 'variable-speed gearing of the friction disc type'; for example, in 1905 there were 10 patents for disc-and-roller designs: see John Brooks, 'Fire Control in British Dreadnoughts: A Technical History' in 'New Researchers in Maritime History, Papers Presented at the Third Annual Conference, 18 March 1995', Royal Naval Museum, Portsmouth, p.1.

The accuracy of the predicted range depended on the disc rotating at constant speed. The driving power was provided initially by a single spring but, by mid-1908, a second spring case had been added, geared to the first. No details of the disc drive were given in the patent, though it appears that a conventional clock mechanism, regulated by an escapement, was envisaged. This was subsequently dropped in favour of driving the 'rotating disc at a constant speed controlled by a governor'. However, the constant speed was not obtained without a struggle against the effects of mechanical friction. Ball bearings were added for the pointer and the disc but not, it seems, for the roller shaft. At the same time, the contact roller spring (which controlled the 'assembly-force' holding the disc and wheel in firm contact) 'has been made adjustable so as to permit of the tension being increased if required'. These modifications from 1908 were not enough. By 1909:

> In order to maintain the load on the clock as far as possible constant at all speeds of the pointer, a compensating brake...is fitted to bear on the rotating disc; the brake is free when the pointer is travelling at its highest speed and bears with increasing load...as the speed of the pointer is reduced.[10]

The disc-and-roller acted as a variable-ratio gear between the spring drive and the frictional loads associated with the roller shaft and range pointer. Thus, as the roller was moved inwards to reduce the rate, the effective load on the drive was reduced as well. Evidently, the governor was unable to prevent the disc-speed increasing as a result, though unfortunately, since no description of this part of the mechanism has come to light, it is not possible to explain why. No subsequent reports of further problems have been found, so it appears that the brake compensated successfully for the inadequacies of the governor. However, the modification was no more than a palliative for excessive friction, probably mainly in the bearings of the roller shaft. These plain bearings were loaded with the full assembly-force, and it is surprising that they too were not replaced with ball-bearings.

It should be recognised that the Vickers designers were faced with a difficult problem in smoothly regulating the limited power available from a spring drive so that the disc rotated at a precise, constant speed regardless of the position of the roller. Even so, the development history of the clock suggests that the full extent of the difficulties were not

[10] The modifications to the Vickers clock are listed in *SPG July 1908*, pp. 8-9: see also *Fire Control*, 1908 (*op. cit.*) p.5; only the *Addenda (1909) to Gunnery Manual* (*op. cit.*) mention the governor and the compensating brake.

at first fully appreciated: and that piecemeal modifications were introduced after the clock entered service until, eventually, the desired performance was obtained.

Speed regulation was a question of static performance; that is, whatever the static setting of the rate (as determined by the position of the roller) the disc had to rotate at the same speed. However, the mechanism also contained two potential sources of dynamic errors i.e. errors induced in the course of changing the rate. While the rate was constant, the roller rolled in a circle on the surface of the disc. To change the rate, the roller had to be dragged sideways. To start it moving, sufficient sideways force had to be applied to make the transition from rolling to sliding, with a corresponding change in the nature of the friction between disc and roller. Then, while the rate continued to change, a somewhat lesser force had to be maintained on the roller to overcome the sliding friction between it and the disc. These forces were exerted against one side of the roller by moving the carriage using the rate-setting handle. They had the unavoidable effects: firstly of increasing the frictional load on the roller shaft: and secondly, by pushing the disc sideways, of inducing additional friction in the upper disc bearing which was not present when the rate was static. Thus, when the rate-setting handle was first turned, the load on the spring drive suddenly increased to a peak value as the roller was first forced sideways; and it then remained at a higher level until the change in rate was completed. Accurate operation depended on the governor - which could not even correct properly for changes in static load - responding rapidly to the initial peak load and correcting for the subsequent sustained load increase.

Once sliding began at the small area of contact between disc and roller, the frictional load on the roller shaft (enhanced by the effects just described) resulted in rotational slippage i.e. sliding at the area of contact so that the edge of the roller moved less quickly than the disc surface beneath it. Thus, even if the governor worked perfectly, the actual clock range would lag to some extent behind the correct range that would be expected from the (changing) clock rate. This would continue until the clock operator stopped turning the rate-setting handle.

Evidence given to the Royal Commission on Awards to Inventors in 1925 establishes that the Vickers clock did indeed 'check' when the rate was altered.

> ...the little stoppage which you notice when you change a variable speed drive of the roller and disc type [such] as you saw on the Vickers clock.

> ...on the Vickers clock the thing you notice is any sudden change, any sudden displacement, and that little roller makes the thing stop altogether, it pauses in a sudden movement.[11]

Thus it appears that a sudden movement of the rate-handle momentarily stopped the rotation of the range pointer. These 'little stoppages' raise two questions. Firstly, what would have been the effect of altering the rate continuously rather than in steps? And, secondly, is it possible to determine whether the check was due mainly to the imperfect response of the governor to the increased frictional load, to rotational slippage between disc and roller, or to both?

ANALYSIS OF SLIPPAGE

Introduction

In the Spring of 1994, while corresponding with Professor Sumida, the present author wrote an initial (and, as it turned out, too simplistic) description of slippage errors in range clocks. In response, Professor Sumida very kindly provided a copy of the M.Sc. thesis written in 1946 by Mr A B (Ben) Clymer, who was an engineer with the Ford Instrument Company; this discussed the operation and accuracy of many different forms of mechanical integrator, including those of the disc-and-roller type, and it was of great assistance to the author in the preparation of a second paper. He is most grateful to Professor Sumida not only for commenting on this himself: but also for obtaining the helpful criticisms of Mr William Newell (formerly Chief Designer and later President of the Ford Instrument Company), Mr Clymer and other colleagues working on the history of American fire control instruments. The descriptions in this Appendix of the physics of friction and slippage in the Vickers clock owe a great deal to the information received during this correspondence: though, as will be explained shortly, the mathematical equations given here are different from those in the Clymer thesis.

Disc-and-Roller Integrators

1. Fig. IX.1 shows the disc with the roller positioned at a distance r along the diametric shaft. If:

    a) r is static i.e. the roller is stationary

    b) the roller is not in or very near to the centre of the disc (this case will be discussed later)

[11] Examination of Mr R H Ballantyne before the RCAI, T.173/547 Part 12, pp. 54-5 and 92-3, PRO.

c) the torque load T on the roller shaft is small enough relative to the assembly force P pressing the disc and roller together such that:

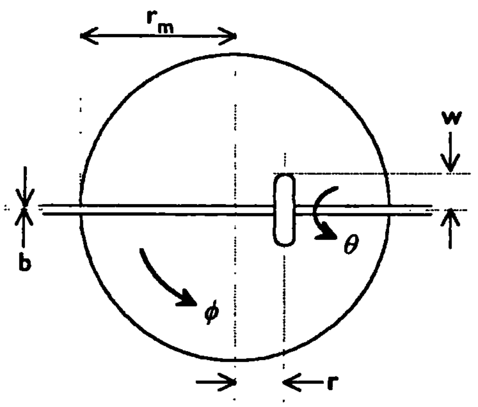


Fig. IX.1

$$\frac{T}{w} \ll \sigma P \qquad \text{(IX:1)}$$

where w is the radius of the roller (also referred to as a wheel) and σ is the coefficient of static friction between roller and disc:

then the roller rolls on the surface of the disc, there is no relative slippage and:

$$w\,\delta\theta = r\,\delta\phi \qquad \text{(IX:2)}$$

where $\delta\theta$ is the angular rotation in the roller shaft caused by a rotation $\delta\phi$ of the disc.

2. If the roller is moving sideways (as would be the case if the rate of a Vickers clock was being changed), there must be sliding contact between roller and disc at the very small area of contact. Thus the magnitude of the frictional force F must be:

$$F = \mu P \qquad \text{(IX:3)}$$

where μ is the coefficient of sliding friction between disc and roller.

3. Fig. IX.2 illustrates the forces and movement at the area of contact; it is almost the same as Clymer's Fig. 1-10. The method of analysis assumes that all velocities are constant i.e. that there are no unbalanced forces. Thus the direction of F must be such that its tangential component exactly balances the force required to overcome the torque load T on the roller. Thus:

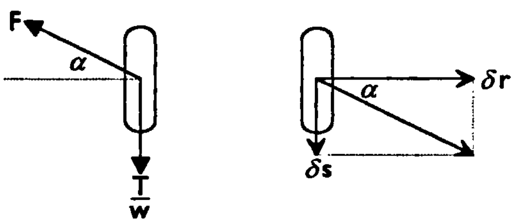


Fig. IX.2

$$F \sin \alpha = \frac{T}{w}$$

and, from equation IX:3

$$\sin \alpha = \frac{T}{\mu P w}$$

Although $\mu < \sigma$, the two frictional coefficients are of the same magnitude. Thus, from inequality IX:1,

$$\frac{T}{\mu P w} \ll 1 \qquad \text{(IX:4)}$$

and so:

$$a \simeq \frac{T}{\mu P w} \qquad \text{(IX:5)}$$

4. The sliding frictional force F is induced by relative motion of disc and roller at the area of contact. With no other forces present, the movement of the roller on the disc must be in exactly the opposite direction to F. This movement consists of two components along and at right angles to the roller shaft. In a small time δt, let these two components be δr and δs, as shown in Fig. IX.2. Thus, from IX:5

$$\frac{\delta s}{\delta r} = \tan a \simeq a \simeq \frac{T}{\mu P w} \qquad \text{(IX:6)}$$

5. Let θ represent the position of the roller shaft if there had been no slippage: and let θ' represent the actual position of the roller shaft. The slippage will result in θ' lagging behind θ. Thus:

$$w\,\delta\theta = r\,\delta\phi$$

$$w\,\delta\theta' = r\,\delta\phi - \delta s$$

and so

$$w\frac{d\theta'}{dt} - w\frac{d\theta}{dt} = -\frac{T}{\mu P w}\frac{dr}{dt} \qquad \text{(IX:7)}$$

Assume that, at time t_1, $\theta'_1 = \theta_1$: and that, by t_2, these have increased to θ'_2 and θ_2 while the roller has moved outwards from r_1 to r_2. Integrating IX:7 after dividing by w:

$$(\theta'_2 - \theta_1) - (\theta_2 - \theta_1) = -\frac{T}{\mu P w^2}(r_2 - r_1)$$

$$\theta'_2 - \theta_2 = -\frac{T}{\mu P w^2}(r_2 - r_1) \qquad \text{(IX:8)}^{12}$$

Thus the error due to slippage is simply proportional to the distance moved by the wheel: provided, as already stated, that the speed of movement is slow enough so that there are no appreciable accelerations in the mechanism.

6. Fig. IX.2 assumes that the roller is positioned for a positive rate and that $r_2 > r_1$. However, the slippage is identical if $r_2 < r_1$. Thus the error ε_2 in the position of the

[12] Clymer's thesis used R for the diameter of the roller. This unfortunately led to the equation for $\tan a$ being formulated as $\frac{r\dot{\theta}}{\dot{r}}$ instead of $\frac{R\dot{\theta}}{\dot{r}}$, where $\dot{\theta}$ represented the rate of change of error in θ. Thus the equation on p.14 equivalent to IX:7 was in error.

roller shaft at time t_2 can generalised as:

$$\text{for +ve } r_1 \text{ and } r_2, \qquad \varepsilon_2 = -\frac{T}{\mu P w^2}|r_2 - r_1| \qquad \text{(IX:9)}$$

7. Notice that, while r remains positive, even if the roller reverses direction, the total error is the sum of two negative errors.

8. If r is negative (the roller is on the other side of the disc) the roller shaft is turning in the opposite direction. Thus θ is falling in value and the error is positive; hence:

$$\text{for -ve } r_1 \text{ and } r_2, \qquad \varepsilon_2 = +\frac{T}{\mu P w^2}|r_2 - r_1| \qquad \text{(IX:10)}$$

9. If the roller passes through the centre of the disc, the shaft changes direction. Thus the errors also change sign. For example, consider the familiar case of a range clock representing two ships passing on opposite courses. Before they pass beam-to-beam, the range-rate is negative: as they pass it is momentarily zero: and subsequently it is positive. Thus, if the clock is started when the target is well before the beam, slippage will result in the clock-range falling less rapidly than the true-range; thus, as the ships pass, the clock will have a positive error. After passing, the clock-range will increase less rapidly than the true-range; thus this negative error will start to cancel out the positive error accumulated as the range fell. When the range returns to its starting value, the error will have been eliminated.

10. As pointed out by Clymer, 'as the roller gets closer to the centre of the disc, the curvature of the arc gets tighter and tighter, and to the degree that the roller is not a point [i.e. the area of contact between disc and roller is not a point] this means you get increased scuffing and higher amounts of friction. This resulted in significant wear and exacerbated the slip problem'.[13] Clearly, when the roller was stationary exactly in the centre of the disc, there could be no rolling and the scuffing and wear were as described; however, there was no rate, so no error could result. If the roller moved slightly outwards to a new static position, it then rotated slowly; looking at the area of contact in plan view, each of the roller's microscopic surface features followed a straight path. In contrast, the surface features of the disc followed curved paths, although these paths were tangential to the paths of the roller features in the centre of the contact area. Thus, especially near the outer

[13] Sumida to Brooks, 23 May 1994.

edges of the contact area, where contact was first made and finally broken, there was some sliding between the microscopic surface features of the roller and disc. However, this contact area was formed by slight distortion of the flat disc surface and the curved edge of the roller; consequently, the contact pressure was greatest in its centre, where there was little or none of the microscopic sliding. Thus the transition to rolling contact would take place as soon as the distance of the roller from the centre was sufficient to allow an area without sliding to develop in the centre of the contact area. It is probable that this distance was little more than the size of the contact area itself, which, with hard metal surfaces, would have been a fraction of a millimetre. Any slipping when the roller was inside this distance would have been at rates too small to produce significant errors.

Thus scuffing and wear at the very centre of the disc, though undesirable, are not themselves indications of significant slippage when the roller was stationary. Equation IX:8 and its derivatives, which predict a zero error when the roller is stationary, appears to be valid in all circumstances.

Vickers Clock

1. In the Vickers clock, the first component of the torque load T on the roller shaft is due to the friction induced in the plain shaft bearings by the assembly force P. If, as shown in Fig. IX.1, the radius of the shaft journal is b and the coefficient of friction in this lubricated bearing is λ, the torque from both bearings is λPb.[14]

2. The second component results from the sideways force exerted on one side of the roller to overcome the component of the sliding friction acting diametrically.[15] From Fig. IX.2, this can be seen to be $F\cos a \simeq F$. The arrangements for exerting this force through the moveable carriage are not clear. Make the worst-case assumption that all the friction is generated near the circumference of the roller. Thus the friction force is λF and:

$$T = \lambda Pb + \lambda.\mu P.w$$
$$= \lambda P(b + \mu w)$$

Substituting in a composite version of equations IX:9 and IX:10

$$|\varepsilon_2| = \frac{\lambda}{w}\left(\frac{b}{\mu w} + 1\right)|r_2 - r_1| \qquad \text{(IX:11)}$$

[14] P is distributed between the two bearings, the ratio depending on the position of the roller.

[15] Remarks by William Newell on John Brooks, 'Slippage in Wheel and Disc Integrators' with Sumida to Brooks, 19 April 1994.

3. At one end of the roller shaft, a small pinion drove a large crown gear. The range pointer was attached to the axle of the crown gear, which turned in a ball bearing. Because of the low gear ration, the friction in this bearing can be safely neglected. By measuring off an enlarged version of the cross-sectional drawing of the clock, it can be established that one rotation of the range pointer (the equivalent to a change in range of 4,100 yards) was produced by 8.02 rotations of the roller.[16]
4. In equation IX:11, replace each r by ρr_m, where r_m is the maximum distance of the roller from the centre and ρ gives the position of the roller as a fraction of r_m. The measured ratio between r_m and the radius w of the roller is 114.5 : 22.0. Likewise, the ratio of b to w is 3.5 : 22.0.
5. Some relevant coefficients of friction are:

Metal to metal, dry	0.15 - 0.20
Smooth surfaces, occasionally greased	0.07 - 0.08
Smooth surfaces, best results	0.03 - 0.036[17]

Even though the roller-shaft and wheel-thrust bearings should have been lubricated regularly, assume a high value for λ (0.08); also use a low value for μ (0.15).

6. Equation IX:11 can now be rewritten as:

$$\begin{aligned}|\varepsilon_2| &= \lambda\left(\frac{b}{\mu w}+1\right)\frac{r_m}{w}|\rho_2-\rho_1| \\ &= 0.08\left(\frac{3.5}{0.15\times 22.0}+1\right)\frac{114.5}{22.0}|\rho_2-\rho_1| \qquad \text{(IX:12)} \\ &= 0.858|\rho_2-\rho_1|\end{aligned}$$

7. ε is in radians. Convert to rotations of the range pointer by dividing by $2\pi\times 8.02$ and then obtain the equivalent range error E by multiplying by 4,100. Thus:

$$\begin{aligned}|E| &= \frac{0.858\times 4,100}{2\pi\times 8.02}|\rho_2-\rho_1| \\ &= 70|\rho_2-\rho_1| \text{ yards} \qquad \text{VI:13}\end{aligned}$$

8. Consider a basic Vickers clock with a maximum rate of 1304 yds/min. Assume that the rate was altered in steps of 100 yds/min. Assume a perfect governor and that the rate change was not too rapid to produce significant unbalanced forces. Then the slippage error arising with each rate step would be only 5.4 yards.

[16] The actual ratio was probably 8 but the measured value will be used.
[17] R B Lindsey, *Physical Mechanics* (Princeton, 1961) p.132.

9. Now imagine a Vickers clock keeping the range of two ships passing on opposite courses. Suppose that the clock rate was adjusted continuously and that the governor was perfect i.e. that slippage errors predominate. Assume also that the initial rate was the maximum that could be set. By the time the two ships passed beam-to-beam, the clock error would only have been +70 yards. As noted earlier, this error would then begin to reduce as the range began to increase. Thus, even in this worst case for pure slippage, the maximum error is less than the normal margin of range error.

CONCLUSIONS

The preceding analysis shows that the slippage due to what may be called steady-state sliding is always small and usually negligible; it cannot have been a significant cause of the check observed when the rate on the Vickers clock was altered. Now compare the relative numeric values for the two frictional components in equation IX:12; they show that the torque load on the disc's spring drive when the roller was sliding was about double that when it was stationary. Thus the change in load was the same as would have been experienced, before the addition of the compensating brake, if the distance of the roller from the centre of the disc had been doubled. The necessity for the compensating brake shows that the governor alone could not fully correct for this change in load, so the disc would have turned more slowly while the roller was moving.

As already mentioned, the sideways force on the disc also imposed a sideways thrust on the top bearing of the disc, which further increased the frictional load on the spring drive. However, it was probably not significant once the original plain bearing had been replaced by a ball bearing.

When the rate setting handle was first turned, the initial drive load was even greater because the roller had to be forced from rolling to sliding on the disc; the force required would be determined by the coefficient of static rather than sliding friction. In addition, no mechanical governor could have reacted instantaneously when the load suddenly more than doubled. The action of the governor depended on detecting an actual drop in speed, in order that the drive power could be increased to restore the speed to a value close to its previous value.[18] Thus the principal causes of the observed check were most probably the initial peak in the load: the delayed response of the governor to this

[18] R L Maxwell, *Kinematics and Dynamics of Machinery* (Englewood Cliffs, 1960) pp.463-7.

initial maximum load: and the inability of the governor to correct fully for the steady-state load imposed by sliding.

Both the initial drop in speed, as well as the sustained reduction while static sliding continued, increased with the magnitude of the rate. They would also have been most apparent when the rate was high. However, when used with a Dumaresq, the normal method of altering the rate of the Vickers clock was in steps, not continuously. In fact, there was a distinct advantage in making each step change quickly. This did not increase or decrease the initial check as the roller started to slide. Nor, at least approximately,[19] did it affect the already small slippage due to sliding (which remained proportional to the size of the rate step). However, a rapid change of rate reduced the time during which the roller was sliding, and therefore the time during which the disc was turning at reduced speed.

Particularly when the rate was high, it must be supposed that the clock stopped completely while the rate was changed. Assuming that the rate handle was moved from one rate to the next in no more than a second, the 'little stoppage' would have resulted in a range error of one sixtieth of the new rate e.g. of 17 yards if the new rate was 1,000 yds/min. Compare this with the errors arising from approximating the true, smooth range curve by a series of straight-line segments of constant rate. The figures in Appendix VIII for this 'stepwise-error' were calculated for the usual worst case of two ships passing on opposite courses. They show that, when the rate was high (about 1000 yds/min.), if the rate was changed in steps of 100 yds/min:

a) the rate was changed about every ½ minute

b) the stepwise-error increased by about 25 yards between each rate change.

Thus, at high rates, the magnitude of the two distinct sources of error were comparable, though the 'stoppage-error' was still less.

While the magnitudes were similar, the signs were sometimes different. When the rate was positive, both errors were negative. When the rate was negative, the rate steps caused the clock-range to decrease faster than the true-range, whereas the stoppage-error resulted in the clock-range decreasing less quickly; i.e. the stepwise-error was still negative but the stoppage-error was positive. The figures in Appendix VIII indicate that, as the rate changed from -1000 yds/min. to zero during the approach, the total stepwise-error

[19] If the rate changed rapidly, the assumption that there were no unbalanced forces no longer holds.

was -172 yards. Using the 'one-sixtieth' rule, the total of the stoppage-errors from the ten changes of rate work out at +92 yards. However, at low rates (when the changes in load on the spring drive were also least) the stoppage errors are less than the pure slippage errors of 5.4 yards per rate step. Thus, using this value for the last three rate steps, the total error is +98 yards. Thus, fortuitously, during the critical period when the two ships were approaching, these errors due to the clock mechanism cancel out more than half of the stepwise error.

While too much should not be made of this result, it does add emphasis to some final conclusions about the Vickers clock. There was little slippage in its variable speed drive, despite its use of plain bearings: but its governor provided inadequate static and dynamic correction for the load fluctuations caused by changes of rate. Yet the normal method of working the clock, by changing the rate in steps, minimised the errors due to poor speed regulation. The clock checked noticeably during a rate step, particularly, it may be supposed, when the rate was high. However, even in the worst case of rapidly changing rate induced by opposite courses, the stoppage-errors were less than those arising from the stepwise change of rate. Even in these most unfavourable conditions, both errors were correctable by one spotting correction. In all other tactical circumstances, the clock errors were negligible. The Vickers clock may have been less than perfect as a mechanism: but its accuracy was quite sufficient for its purpose.

APPENDIX X

BATTLE PRACTICES

In 1899, HMS *Caesar* of the Mediterranean Fleet 'carried out the first long range firing under weigh at a moored target at ranges up to 6,000 yards'.[1] *Canopus* (Mediterranean) and *Majestic* and *Mars* (Channel) all carried out long range firing in 1900[2] and, from 1901:

> Long-range firing...practice is to be carried out once a year...by those ships...whose displacement exceeds 4,000 tons....Each ship is to make three runs [at 12 knots] on a straight course, opening fire at 6,000 yards.

Initial target bearings on and off the bow resulted in rates between 239 and 405 yds/min.,[3] which were not undemanding for ships with little more than a coarsely graduated 4½-foot rangefinder.

The courses followed by *Venerable* at Prasa Island in 1904 were similar for the full charge firings at 8,000 yards; speed was 12-15 knots and target was kept about one point on the bow. However, the conditions when firing half charges at 3-4,000 yards were much more taxing, in one case causing the rate to swing from 287 yds/min. closing to 395 yds/min. opening.[4] Of course, an island target presented no problem of determining enemy course and speed. On the other hand, the rates were typical of many likely battle conditions i.e. courses initially converging followed by one or more turns onto roughly parallel courses. Later in 1904, battle firings were held in the different fleets but, according to Percy Scott:

> It is impossible to make a comparison between the squadrons, as they all did it in different ways, at different ranges and at different sized targets.

[1] Admiralty, Naval Staff, Gunnery Division, *Extract of Gunnery Practice in Grand Fleet 1914-18. Battleships and Battlecruisers*, March 1922, p.2, ADM 137/4822, PRO.
[2] 'Schemes of Communications', f.11 in 'Communication and Control of Gunfire in Action' in ADM 1/7756.
[3] *Manual of Gunnery for His Majesty's Fleet 1901* (London, 1901) p.382, Ja254, AL.
[4] Admiralty, Gunnery Branch, *Interim Report of the Mediterranean Committee on Control of Fire, &c*, forwarded 18 February 1904, pp. 17-18 in ADM 1/7756.

For example, ships of the Atlantic Fleet, steaming at 14 knots and altering course 4 points after 4 minutes firing, made 10.1% hits on a 2,700 sq. ft. target at 5,500-6,000 yards.[5]

Uniform rules for Battle Practice were laid down for the following year, using a moored target 90 feet long by 30 feet high. Each firing ship was to be led, at 15 knots, by a ship carrying the Chief Umpire, who would draw a course from a number of prepared schemes; each scheme included a change of course after about five minutes' firing.[6] In Scott's opinion: 'The general result...was very bad, 6,252 rounds were fired and only 1,078 hits made':[7] although, at 17.2%, it was an improvement on the previous year and it is probable that many of the ships taking part had not yet calibrated their guns. In 1906, the firing ship was again to be led by the Umpire, the former 'should be furnished beforehand only with the knowledge contained in the general rules of battle practice'. After an approach with the target almost ahead, the firing ship turned by 51° to 56° to bring the full broadside to bear at a range of 6,050 yards. After firing for five minutes with the range falling to about 5,000 yards, a 2-2½ point turn caused the rate to swing from about 200 yds/min. closing to 225 yds/min. opening, so that the range had increased again to almost 6,000 yards when firing ceased after a further 4 minutes. The allowance for the 12-inch guns was four rounds per gun: while each 6-inch on the bearing side was allowed 16 rounds, sufficient for sixteen full 6-inch salvoes at half-minute intervals throughout the firing.[8]

The 1907 Battle Practice was noteworthy as the first in which an all-big-gun ship participated (*Dreadnought* came top): and the last in which the target was moored. The conditions were officially described as 'more severe' than in 1906;[9] while the range was still about 6,000 yards, the rate, up to 400 yards per minute, was increased. On average, the 12-inch guns made 29.1% of hits from rounds fired, although *Britannia*, 'the only ship at present fitted with improved 12-inch turret training gear and the latest 12-inch sights', achieved 43.8%.[10]

> In the battle practice of 1907, there was generally a noticeable improvement in the organisation of the control arrangements over those of the previous year...weaknesses

[5] Percy Scott, 'Gunnery Lecture No. IV', 28 February 1905 in *Gunnery* (privately printed, June 1905) pp. 55-6, Craig-Waller Papers (courtesy Commander Michael Craig Waller).
[6] 'Revised Rules for carrying out Battle Practice', 6 May 1905 in *Principal Questions dealt with by Director of Naval Ordnance*, January to December 1905, p.476, PQ16, HRO.
[7] Percy Scott, 'Gunnery Lecture No. 5', 24 February 1905, p.78, *Excellent* Historical Library.
[8] Rules of 1 February 1906 in 'Revised Rules for Battle Practice 1906' in ADM 1/7896.
[9] Admiralty, Gunnery Branch, *Results of Battle Practice in His Majesty's Fleet 1907* in Ja156, AL.
[10] Jellicoe to Fisher, 17 November 1907 in FISR 8/27 (F.P. 4849) CC.

> still exist in the faulty corrections of fire....Too high a percentage of hits is aimed at, with the result that a large proportion of shots go "over".[11]

Arthur Pollen took a much more critical view of what he called 'the kindergarten conditions of battle practice'[12] though he also acknowledged 'the astounding variation that the present tests...exhibit'.[13] Were his criticisms justified? Firstly, it must be remembered that the 1907 practice was also the first in which the 9-foot rangefinder was widely available to supply accurate ranges and (by timing) rates. Secondly, the elaborate arrangements to keep secret the firing ship's course and speed have already been described; these ensured that the rate had to be obtained during the actual firing. Thirdly, the following quotation suggests that rate finding, even with a moored target, was made as difficult as in action.

> Fire was opened at ranges between 7,000 and 8,500 yards, with the target bearing 45 degrees to 60 degrees before the beam, the minimum range being about 6,000 yards. The speed was 8 to 11 knots, *the exact amount being unknown at the control position* [author's italics] and a turn of two to three points was made during the run.[14]

These speeds and target bearings equate to a rate between 190 and 330 yds/min. and emphasise that, when the target was moored 'change of range is far more rapid than in many cases where the target will be moving'.[15] Furthermore, because the control personnel were kept in ignorance of their own speed, they were obliged to obtain the rate (from timed ranges), then to set the Dumaresq and use it to keep the rate as the target bearing altered. Assuming that the same problem was posed to all ships in Battle Practice, it may be concluded that, even in the last year of moored targets, the exercise was not as childishly simple as Pollen alleged.

Nonetheless, at the close of 1907, the DNO, Jellicoe, accepted that 'having the target moored is the one practical blot on our practice', particularly since it precluded estimation 'of change of range due to alteration in course and speed of enemy'.[16] Unfortunately, after 1907, information on the purpose, conditions and results of Battle Practice with towed targets is even more incomplete than for the earlier years. Although

[11] Admiralty, Gunnery Branch, *Fire Control*, May 1908, p.47 in ADM 1/8010 and T. 173/91, Part I, PRO.
[12] 'Jupiter Letter II', January 1906 in Jon Sumida (ed.) *The Pollen Papers* (London, 1984) p.77.
[13] Pollen to Admiral Wilson, 17 December 1907, T. 173/91 Part VII.
[14] 'Instructions to Officers in Battle Practice in HMS "Revenge" ' in Admiralty, Gunnery Branch, *Half Yearly Summary of Progress in Gunnery*, January 1907, p.48, AL. The best run produced 50 per cent of 13.5-inch hits and 44 per cent of 6-inch hits, a remarkable result with guns which first saw service in 1892. *Revenge* was the gunnery ship attached to *Excellent*.
[15] Arthur Pollen, 'An Apology for the A.C. Battle System', 1907 in *PP* (*op. cit.*) p.151.
[16] 'Memorandum by Director of Naval Ordnance on Towing Targets' in Navy Estimates Committee, *Report upon Navy Estimates for 1908-9*, FISR 8/11 (F.P.4724).

the results of Battle Practice were published each year, listing ships in order of merit, their scores were expressed in points. The method of converting actual hits and ricochets on the target (as well as estimated hits on an imaginary ship) into points was, however, not revealed either to the public or even to senior officers afloat. While the conditions of the practice also varied from year to year, the publication of the results demanded that there was no apparent falling-off in performance, and it was admitted that the points were adjusted to avoid this.[17] Furthermore, the conditions each year were kept secret from the participants until the last moment; perhaps as a result, there are no clear sources for how the conditions changed after 1907, although the following account presents what evidence has been found.

In the system of practices established by Jellicoe as DNO and Scott as ITP:

> The spirit of emulation...is fostered by making all the practices competitive...and the rules...provide...for the competition being fair whilst making the [battle] practice at the same time resemble actual conditions of battle as far as can be done under peace circumstances.[18]

The competition was between all the major ships of the fleet, battleships and cruisers, some modern, some with old guns on obsolete mountings; as the table (based on the Battle Practice Reports) shows, dreadnoughts did not reach even equality in numbers until 1912.[19]

Year	Dreadnoughts (battleships and battlecruisers)	Predreadnought battleships (12-inch)
1907	1	28
1908	2	26
1909	4	30
1910	8	26
1911	14	22
1912	17	17
1913	15	19

Thus, until 1911, Battle Practice was dominated by the older types of ship with their simple fire control, mixed armament and many 6-inch guns; the limited effective range of

[17] Vice Admiral Jellicoe to the Secretary of the Admiralty 18 December 1911 and Minute by Captain Moore, DNO, 12 January 1912 in 'Gunnery in the Royal Navy, Conference at the Admiralty Dec., 1911/Jan. 1912. Report and action' in ADM 1/8328.

[18] *Paper prepared by the Director of Naval Ordnance and Torpedoed for the information of his Successor*, July 1907, pp. 30-31, AL.

[19] *Results of Battle Practice 1907 to 1913* are bound together in Ja 156, AL (*op. cit.*).

their secondary armament was certainly one factor working against any proposals to increase the range.[20] Furthermore, the emphasis on fair competition may have precluded conditions which gave undue advantage to ships with the latest equipment. Thus, especially after the introduction of the additional special firings in 1910,[21] Battle Practice should not be seen as an engine forcing the pace of progress: but as a test that equipment was effective in general service. It followed, rather than led, innovation.

A manageable towed target, 90 feet by 30 feet, already under development as a matter of 'supreme importance' in 1907, was ready for the 1908 Battle Practice.[22] According to Pollen, the maximum rate was reduced to 175-200 yds/min., while the average hitting rate fell to 17-20%.[23] However, these numbers give little indication of the actual conditions. The practice introduced two major new difficulties.

> For this competition, the firing has [hitherto] been carried out from one broadside only; it is proposed to let both broadsides fire; this will call for more skill on the part of officers and men, since the turn of the ship will considerably alter both the range and also her speed.
> ....Arrangements will also be made to test the secondary fire control arrangements of ships in the event of the primary system failing. [24]

After joining the Home Fleet in October 1908, *Indomitable* carried out her first Battle Practice on 16 January 1909; however, this was part of the 1908 series, in which she came first. Her remarkable firing, described in a letter to Fisher, confirms that a large turn was made half way through.

> ...of the 15 rounds fired on the first run of 4 minutes, 13 were direct hits on the target....a "record" under present Battle Practice conditions (with speed of target 8 knots, course and speed unknown to firing ship, "Indomitable" steaming 15 knots and distance of target 8,300 to 9,600 yards). In the second run of 4 minutes after turning 18 points, 5 hits were scored out of 16 rounds. This less good result was due to a small error in spotting...[25]

In one run, almost certainly the second, the firing ship and the target must have been on nearly opposite courses, thereby inducing the rapid change of range-rate to which Pollen

[20] In 1911, Jellicoe was concerned lest increasing range and a reduction in the points awarded for 6-inch hits 'discourage the training of the Officers and Men concerned with the secondary armament if it considered that they will be of value in Action'. Jellicoe to Secretary, 18 December 1911 (op.cit.).
[21] See Chaper 3.
[22] *DNO for Successor*, July 1907 (*op. cit.*) p.31 and November 1909 p.20. Pollen himself acknowledged the difficulties of handling targets, especially when towed, except in good weather: *PP*, 'Reflections on an Error of the Day', 1908, p.182.
[23] *PP*, pp. 239, 280 and 329.
[24] 'Memorandum by Director of Naval Ordnance on Gunnery of the Fleet' in *Navy Estimates 1908-9* (*op. cit.*) pp.111-2. For the intention to test an alternative system, see also *Fire Control*, 1908 (*op. cit.*) p.4.
[25] *Results of Battle Practice 1908*; *Dreadnought* was fourth. Rear Admiral Inglefield to Admiral Fisher, 18 January 1909 quoted in Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) p.160.

attached so much importance. *Inflexible*, after delays in commissioning to repair damage from her gun trials, made her first Battle Practice off Malta in March 1909.

> A long swell the ship being somewhat light, made her distinctly lively, and ½ ° to 1½° roll and 1° to 2° pitch, with considerable scend at times, made laying and training difficult.

She made only 4 hits from 29 rounds.[26] The contrast with *Indomitable* was no doubt in part due to rougher conditions, but was probably made worse by *Inflexible's* less efficient turret training gear.

Ranges, courses and speeds differed little in 1909. The target was still towed at 8 knots at a range of 'about 8,000 yards'. The firing ship worked up from 8 to 15 knots during the eight-minute initial approach, when the rate was at most 300 yds/min. Firing was limited to two bursts of four minutes each, separated by the 18-point turn. Transmitters were disabled to test alternative methods of communication.[27] In his memoirs, C V Usborne, then gunnery lieutenant in *Bellerophon*, gave a vivid description of Battle Practice, which establishes that effects of casualties were also simulated.

> One of the umpires was with me in the control position. His duty, as I well knew, would be at some critical juncture of the proceedings to inform me that I was 'dead', whereupon I must cease to function, and some other must take my place.
> ....
> ...our leader led us round so as to bring the target on the other side....when I was ordered officially to die we had already expended all the ammunition allowed.
> ...18 hits on the target. Out of 40 rounds that was a very high percentage for long range firing...we tied with the *Dreadnought*.[28]

Unlike the dreadnoughts, some older ships for the first time did their practice in rough weather, which exposed problems with ranging, plotting, aiming and spotting.[29]

In November 1909, Admiral May (C.-in-C, Home Fleet) proposed that, since 'at about 8000 yards...the "DREADNOUGHT" class firing overwhelmed the target', a new long range battle practice at 10,000 to 12,000 yards should be introduced for 12-inch and

[26] John Roberts, *Battlecruisers* (London, 1997) p.122. Staff of ITP, 'Battle Practice, 1909', Lecture 1, f.2, MS 19, *Excellent* Historical Library, copy courtesy Professor Sumida. *Inflexible* does not appear in the results of Battle Practice for 1908 or 1909.
[27] *Results of Battle Practice 1909*. Letters from Vice-Admiral Berkeley Milne 28 October 1909 and Admiral May 31 October 1909: minute by Rear-Admiral Peirse (ITP) 23 November 1909 all in 'Revised Instructions for the Expenditure of Heavy and Light Gun Ammunition' in ADM 1/8065. ITP, 'Battle Practice, 1909' (*op. cit.*) f.18.
[28] Vice-Admiral C V Usborne, *Blast and Counterblast* (London, 1935) pp.8-12. Usborne states that this practice was held 'a year or two before the War' under Captain Hugh Evan-Thomas, but everything points to the 1909 practice; see also *Results of Battle Practice 1909* and Andrew Gordon, *The Rules of the Game* (London, 1996) pp.372-4.
[29] ITP, 'Battle Practice, 1909', Lecture 1, ff.2-5.

9.2-inch guns only. This would be additional to the existing medium range practice, which should be retained for all ships but made more difficult by exercising the effects of damage, casualties, and changes of target course.[30] Rear-Admiral Peirse, the ITP, did not concur with the introduction of longer ranges, in part because they would result in fewer hits and so make the detection of errors more difficult. However, he did confirm that his proposals for 1910 included most of the tests suggested by May to simulate the effects of enemy fire.[31]

It is regrettable that little information has been found on the Battle Practice conditions for 1910, since 'the conditions...differed considerably from those of former years'.[32] *Vanguard* fired at ranges 'far longer' than 7,500 yards (during the first run) and in all made 10 hits from 21 rounds, which placed her third. The points scored suggest that the best ships were still making over 40% hits: which result appears to justify Admiral May's renewed warning that 'too much stress should not be laid on deductions drawn solely from Target Practice under easy conditions in peacetime'.[33]

The conditions in 1911 were again different from the year before. The range was increased significantly, to an average 9,300 yards,[34] while the effects of failures were still being simulated.[35] Only average figures for the percentage of hits are available, but they suggest a considerable reduction from previous years.

> <u>Battle Practice</u>. 12" guns fired nearly 800 rounds. On Run I they got about 10% hits, & on Run II (short range) about 17%.
>
> ....
>
> <u>Ranges</u>. Dreadnoughts open at 9200.
> Squad^{n} firing has been opened at 12,000.[36]

> The Return of Battle Practice for 1911 shows that, on the First Run the 12" guns missed the target 87 times, and the 6" guns 94 times, out of every 100 rounds fired.[37]

[30] Letter from Admiral May, 31 October 1909 (*op. cit.*).
[31] Minute by ITP, 23 November 1909 (*op. cit.*).
[32] *Results of Battle Practice 1910.* The first three ships were *Agamemnon* (316.3 points), *Invincible* (286.0) and *Vanguard* (196.6).
[33] 'Remarks on Local Control by Commander F.C. Dreyer RN of HMS "Vanguard" ', 5 September 1910 and Minute by Admiral May 1 October 1910 in 'Local Control of Turret Guns. Special Firing by HMS "Vanguard"... ' in ADM 1/8147.
[34] *Results of Battle Practice 1911.* Admiralty, Naval Staff, Gunnery Division, *Progress in Naval Gunnery 1926*, Plate 1, ADM 186/271.
[35] During her Battle Practice, *Prince of Wales* switched from her fore to aft rangefinder. Captain Hopwood to VAC Atlantic Fleet, 20 November 1911 in T. 173/91 Part III.
[36] Manuscript notes 'Recent gunnery practises [*sic*]. (Capt. C Fuller 6.6.12)' in DRAX 1/9, CC. The ranges and date indicate that these concerned the 1911 rather than 1912 practices.
[37] Vice Admiral Percy Scott, Rear Admiral R H Peirse and Lieutenant A Gilbert, 'Final Report of the Committee on Director Firing', 15 November 1912, MB1/T22/161, Battenburg Papers, University of

There is clear evidence in the surviving documents of serious disquiet. Jellicoe (now VAC Atlantic Fleet) commented that:

> There has been a distinct reduction in the number of hits made on Battle Practice Targets during the last two or three years. This is due to two causes:-
> (1) The conditions have been made more difficult year by year, and
> (2) There have been innovations in training which have not been altogether beneficial in producing hits on the Target.
> The increase in range has, in my opinion, gone too far, especially as regards ships armed with 6" guns.[38]

Unfortunately, it is difficult to reconcile the last two quotations with the official results, in which the predreadnoughts, with many 6-inch guns, obtained 16 of the top 20 places. Perhaps they made many more than 6% hits in the second, short-range run; or, in converting hits into points, too much allowance was made for the initial long range. Only the following comment by the DNO, Captain Moore, provides any explanations for the poor results obtained by the dreadnoughts:

> ...it is true the actual score figures are lower, but can largely be accounted for by the reduced value of the ricochet hit, the increased difficulty of the competition accounting for the remainder.[39] .

The concern over the Battle Practice results prompted the setting up of a Conference on Gunnery at the end of 1911, chaired by Rear Admiral Sir George Warrender; among the members was Frederic Dreyer (then Commander of *Vanguard*) representing Jellicoe. While the report by the conference made many recommendations concerning training, towing of targets, etc., it does not shed any further light on other reasons for the marked reduction of hits, nor does it contain any specific criticisms of fire control gear.[40]

In 1912, there was a modest reduction in the average range (from 9,300 to 8,600 yards) while the number of hits per gun per minute recovered decisively from .08 in 1911 to .19 in 1912 (the top ship attaining .24 at 8,500 yards).[41] A record kept by Captain Craig of *Orion's* battle practice shows that she plotted the 8-knot target for 12 minutes as the range fell from 11,000 to 8,000 yards. Steaming at 15 knots, she then followed the

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Southampton.

[38] Letters to the Secretary of the Admiralty from the C.-in-C. Home Fleet 18 October 1911 and VAC Atlantic Fleet 18 December 1911: Minute from Captain Moore, DNO, 24 October 1911: in 'Gunnery Conference 1911-1912' (*op. cit.*).

[39] DNO's minute, 12 January 1912 (op.cit.)

[40] 'Conference on Gunnery', report n.d. but early 1912, in 'Gunnery Conference 1911-1912'.

[41] *PNG 1926* (*op. cit.*). Plate 1 is a graph of 'Hits per gun per minute on a ship of "Queen Elizabeth" class at 60° inclination' against range and was drawn to compare the results of single ship practices pre-and post-War. While showing the results for 1911-1913 in terms of this standard target, the actual rates of hitting on the smaller pre-War targets must have been lower.

leading ship's turn of 22° outwards and fired her practice allowance of 40 rounds in eight salvoes in 6 mins. 45 secs., the average, near-constant rate being only -125 yds/min. She made 10 hits plus 3 ricochets, which equates to 25% of hits to rounds fired (27.3% if ricochets are valued at 0.3 as in the Gunlayer's Test). Other ships probably had to contend with higher rates, though the limit was still only 350 yds/min. Captain Craig's notes include a table of results from 22 ships which is ordered very similarly to the final published result in which *Orion* was placed second to *Colossus*.[42] Assuming the 15 dreadnoughts in the table all fired their full allowances, the average result is 17.7% (hits only) or 20.6% (hits plus ricochets at 0.3). This was an improvement on the previous year, although the target length had been increased from 90 to 127 feet 'so as to ensure better spotting results by obtaining many hits now lost for direction'.[43] However, it was worse than achieved earlier at very similar ranges with much more drastic alterations of course; in 1908, *Indomitable* made 58% of hits, while in 1909, both *Dreadnought* and *Bellerophon* got 45%. Unfortunately, no other explanations have been found for this apparent decline in gunnery standards, other than the disruption caused by exercises simulating the effects of damage and casualties.

Information remains sparse for 1913, the final full Battle Practices of the pre-War years, although it was supposed to introduce 'new elements of actuality'.[44] The average range remained at 8,600 yards, but the average hits per gun per minute increased to .23, while the top ship, *King George V*, made .36. By simple proportion from the previous year's average results, these figures give an average of 21% and a maximum of 30% direct hits on the target. However, *The Times* credited the *Orion*, which was eventually ranked fifth, with 40-45% hits,[45] so perhaps results were again comparable with 1908-9. In 1914, Battle Practice had probably not even begun before it was interrupted by the real thing. After hostilities had ended, Jellicoe recalled that:

> The effective range of the gun and the torpedo was quickly shown to be much greater than had been considered before the War.

adding, in a footnote:

[42] Battle Practice Chart, HMS Orion 1912 and Table 'Class 1 Ships', Craig Waller Papers. DNO's minute 24 October 1911 (*op. cit.*). *IDNS* (*op. cit.*) p.226. *Results of Battle Practice 1912*. *Colossus* made 8 direct hits but 8 ricochets.
[43] DNO's minute, 12 January 1912.
[44] *The Times*, 27 June 1913, p.77.
[45] *PNG 1926* (*op. cit.*). *Results of Battle Practice 1913*. *The Times* (*op. cit.*)

> In pre-War days our Battle Practice had been carried out at a range of 9500 yard...[46]

This probably refers to the 1911 practice, but even if it alludes to the intentions for 1914, it confirms that the gunnery part of Battle Practice always remained a test at 'effective' rather than long range.

[46] Admiral Viscount Jellicoe, *The Grand Fleet 1914-16. Its Creation, Development and Work* (London: Cassell, 1919) p.38.

APPENDIX XI

RANGES

Captain Bacon, DNO, on battle ranges, 1908:

> Bacon...argued that sophisticated fire control methods were unnecessary because poor visibility in the North Sea, where he anticipated that the next naval war would be fought, would restrict battle ranges. "Our guns", he maintained, "are enormously over-ranged already".[1]

Captain Hughes-Onslow on visibility:

> ...in the North Sea...on 7 or 8 days out of every 10, the visibility does not exceed 8,000 yards.[2]

Admiral May on engaging in thick weather, 1910:

> When Fleets meet in weather which is such that visibility is less than the effective range of guns, there is no approach, there is no time to plot, and if the course of one Fleet happens to be so favourable that it may be maintained, there is yet no justification for that Fleet to withhold its fire for one instant longer than it takes to get the guns to bear and a range on the sights, for it must be remembered that six broadsides are set aside for every three minutes calculations.[3]

Admiral May on the 1909 Battle Practice and engaging in clear weather:

> In the recent Battle Practice at about 8000 yards...the "DREADNOUGHT" class firing overwhelmed the target. There can be no doubt that the opening range in action would be not less than 12,000 yards with the 12" and 9.2" in clear weather.
>
> ....
>
> Rangefinding, plotting and so forth are calmly carried on at a range which for "DREADNOUGHTS" is not merely decisive but annihilating.[4]

[1] Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) pp.151-2.
[2] 'Fire Control. An Essay by Captain C. Hughes-Onslow, R.N.', 'General Remarks and Conclusions on Plotting', p.1, 1909, PLLN 1/5, CC.
[3] Admiral W H May to the Secretary of the Admiralty, 25 April 1910 in 'Gunnery: Effects on...plotting...&c of new developments in Fleet Tactics', ff.51-2 in ADM 1/8051, PRO.
[4] Admiral May to the Secretary of the Admiralty, 31 October 1909 in 'Revised Instructions for the Expenditure of Heavy and Light Gun Ammunition' in ADM 1/8065.

Admiral May following the 1910 Tactical Exercises:

> ...whatever system of keeping the gun sights correctly set be adopted, the necessity of a Range Finder capable of accurate employment during the Approach remains.... reasonable accuracy at 15,000 yards is required.[5]

Captain Moore, DNO, on the lessons of the Tactical Exercises:

> It is interesting to note how small was the error in estimating the enemy's course by eye....It was remarkable also that the error was generally smallest between 8,000 and 10,000 yards, the accepted battle range of today....[6]

Admiral May in 1911 on assumptions concerning effective range for Tactical Exercises:

> In clear weather...no gunfire has been allowed outside 10,000 yards.[7]

Vice-Admiral Jellicoe's War Orders when commanding 2nd Division, Home Fleet, 1911-12:

> RANGE FOR ENGAGING
>
> A slow fire will be opened by guns of 9.2" and above at 15,000 yards providing weather conditions and the motion of the ships permit. The fire will be quickened as the range and rate of change are found and decrease, and at 13,000 yards to 12,000 yards the maximum rate of fire should be established if hits are being obtained. In view of the torpedo menace, it is not intended to close to less than 7,000 yards under ordinary circumstances...[8]

Admiral Callaghan's supplement to Admiralty Instructions, October, 1913:

> For ships of the all big gun type in fine clear weather, deliberate fire may well be opened at about 16,000 yards; 8,000 to 10,000 yards should suffice for effective range at which superiority of fire may be established; ranges below 8,000 yards are to be expected towards the later stages of the action in order to press home advantage and obtain decisive results.[9]

Home Fleet Order on Fire Control, November 1913:

> ...it has been suggested that under favourable conditions of weather and visibility at ranges below 10,000 yards a bracket of 200 yards may be sufficient, *if* a good plot has been obtained and the rangefinders are well together. These conditions however can

[5] May to Secretary 25 April 1910 (*op. cit.*), f.60.

[6] Minute by Captain A G H W Moore received 4 May 1910 in 'Effects...of new developments' (*op. cit.*)

[7] Admiral W H May, *Notes on Tactical Exercises, Home Fleet, 1909-1911*, p.3, Eb 012, AL.

[8] A Temple Patterson (ed.), *The Jellicoe Papers, Volume I* (Navy Records Society, 1966) p.24.

[9] Memorandum 'Conduct of a Fleet in Action. Commander in Chief's Instructions (Supplementary to the Instruction issued by the Admiralty...October 1913)' attached to Captain H G Thursfield, 'Development of Tactics in the Grand Fleet', Lecture I, 2 February 1922, THU 107, NMM.

rarely be those of action, as, when the visibility is good, fire will probably be opened at much greater ranges.[10]

Captain F C T Tudor, DNO, November 1913:

I am very strongly of the opinion that the probability that the modern battleships and battlecruisers can knock themselves out...at say 9,000 yards will merely lead...to ships opening at much greater range than 9,000 yards.[11]

Vice-Admiral Jellicoe's Grand Fleet Battle Orders, 1914:

OPENING FIRE - THE BATTLEFLEET

...On a clear day and unless the enemy opens earlier, 13.5-inch gun ships will open deliberate fire at 15,000 yards, 12-inch gun ships at 13,000 yards.
If the enemy opens fire at greater ranges...fire is to be opened at once in reply....

CONDUCT OF A FLEET IN ACTION...

...In clear weather we hope that deployment at long range may give us the initial advantage in gunfire it is so important to obtain, but there can be no doubt that we must gradually close the range to obtain decisive results....

...BATTLE TACTICS...

...Generally speaking, so long as the action is being fought on approximately parallel courses, the whole fleet should form one line of battle, and the range should be between 12,000 and 9000 yards.

INTENTIONS AS REGARDS DEPLOYMENT

...Assuming good visibility and favourable weather, and non-deployment earlier on the part of the enemy, I shall probably deploy at a range of about 16,000 yards so as to be in a favourable position to open fire in good time, whilst, if the enemy delays his deployment, our fleet will be able to concentrate its whole force on the leading ships of his columns.
I attach the greatest importance to making full use of the fire of our heaviest guns in the early stages at long range. Close action is to the German advantage, if they intend to use large numbers of auxiliary craft to strengthen the attack on our fleet....[12]

[10] *Home Fleet General Orders*, '14. Fire Control Organisation', 5 November 1913, p.3 in DRAX 1/9, CC.
[11] DNO's minute, 18 November 1913 in 'Important Questions dealt with by DNO...Vol. II', 1913, AL.
[12] *Jellicoe Papers I* (*op. cit.*) pp.59 and 61-3.

APPENDICES TO CHAPTER 4

APPENDIX XII

A C AND ARGO: TECHNICAL NOTES

I. TWO-POSITION RANGEFINDER: SYNCHRONISATION

At a bearing instrument, the observer, by pressing one of the seven transmitter keys, could indicate that the selected target feature lay somewhere in a band 15" of arc in width. If the target was moving across the telescopes' fields of view, it was necessary for both observers to press their keys almost simultaneously, otherwise additional angular errors would be introduced equal to the angular movement in the times between the two keystrokes. Assume that the target for synchronisation accuracy was also 15".

Consider first the case when the ship has no yaw. The following calculations are based on Pollen's own example in his 1904 pamphlet 'Fire Control and Long Range Firing' of two ships on roughly opposite courses.[1] When in positions A_2 and B_2, the values to be inserted in equations 2:3 and 2:4 are:

$e = 12$ knots $\qquad \iota = 125°$

$s = 17$ knots $\qquad \beta = 74°$

$R = 8,490$ yards

giving:

$$\dot{\beta} = 6.0\ °/\text{min. or } 6.0\ '/\text{sec.}$$

If the target was moving across the field of view of the telescopes at this speed, it would traverse 15" in $\frac{15}{6.0 \times 60} = .042$ secs. or 42 msecs.

In practice, movement due to yaw was much greater than this; in *Jupiter*, yaws of 2°/sec. or greater were experienced. This would require a synchronisation accuracy of $\frac{15 \times 1000}{2 \times 3600} = 2.1$ msecs.

[1] Arthur Pollen, 'Fire Control and Long Range Firing...', December 1904 in Jon Sumida (ed.) *The Pollen Papers 1901 - 1916* (London, 1984) Fig.4, p.48.

2. A C DUAL GYROSCOPES

Plate 13 (which is taken from the 1906 patent) gives a plan view of the A C dual gyroscope directional reference.[2]

The whole mechanism was mounted on a chassis 5 which was fixed in the ship. The action of the gyroscopes kept the arm 44 pointing in the same direction, even as the ship yawed beneath it. In the *Ariadne* gear, this arm was itself a contact arm working over a divided contact arc connected by gearing to the training drive of the rangefinder mounting.[3] The divided arc had a narrow gap in its centre. If the rangefinder was bearing correctly, the tip of the arm lay in the gap. If the ship yawed, the arc rotated beneath the arm; thus the arm made contact with one segment of the arc. This closed an electric circuit which energised one of the two clutches in the rangefinder training gear, thereby training the rangefinder in the direction necessary to return it to its correct bearing.

Initially, both gyroscopes were clamped with their rotational axes parallel to the keel. Then each in turn was released to run freely, the free gyro providing the directional reference. While still clamped, each gyro was driven up to speed by an air blast. As each gyroscope was unclamped, it was coupled through a light clutch and coupling rod to the contact arm. Once connected, frictional torque (due mainly to the contact pressure of the arm on the divided arc but to a lesser extent to friction in the various gyro bearings) would tend to make the gyro precess so that its axis of rotation was no longer horizontal. Before this inclination could affect directional accuracy, at fixed intervals of four minutes the other gyroscope was connected in its turn. The disconnected gyro was then reclamped so that its axis was once more parallel to the keel; and then again driven up to speed.

The direction of the contact arm was determined by that of the first gyro to be unclamped i.e. by the direction of the ship's head at that moment. When making a straight-course plot, it was desirable that this direction should coincide with the mean-course line. Subsequently, as each gyro was connected alternatively, the ship's head might or might not have been in the same direction. Even so, differences in the directions of the gyros as each was unclamped in turn did not induce any change in direction of the control arm.

[2] Patent 23,846/1906 applied for 26 October, complete specification 25 May 1907.
[3] 'The Pollen Aim Corrector' in *Notes, Correspondence, Etc. on the Pollen A.C. System installed and tried in H.M.S. Ariadne December 1907 - January 1908*, pp.15-19 and Figs. 12-14, DRAX 3/1, CC.

3. HUNTING BY THE A C RANGEFINDER MOUNTING

The general arrangement of all the A C rangefinder mountings was similar (Plates 18 and 19). Its foundation was a pedestal screwed to the deck. Within this rotated a vertical, inner tube, the position of which was controlled by the gyroscope so that it remained fixed in space even while the ship yawed beneath it. On this tube was a second, outer tube which carried both the rangefinder itself and a seat for its operator; the latter could train himself and the rangefinder with the power-training gear, which rotated the outer tube relative to the inner.

In *Ariadne* (and the *Natal* mounting must have been very similar), the inner tube was trained by means of a shaft carrying an armature plate placed between two counter-rotating electromagnetic clutches. If the inner tube was correctly aligned with the gyro-controlled contact arm, neither clutch was energised and the armature plate remained stationary. If the inner tube and the contact arm were not in alignment, the arm made contact with one segment of the divided arc described in Note 2; current therefore flowed in a relay switch which energised one of the clutches. The selected clutch then drove the armature plate in the correct direction to realign the narrow gap in the divided arc with the contact arm controlled by the gyros.[4]

The operation of this basic type of 'bang-bang' servo has two disadvantages. Firstly, it is inherently jerky. The clutches rotate at constant speed, which must be fast enough to keep up with the most rapid yaw. However, if the yaw is slower, the clutches must be energised intermittently, in order to produce the required rate of training by a series of short steps. The frequency and duration of the steps depend on the inertia of the mounting, the amount of slip at the clutch faces and on the relative dimensions of the gap in the divided arc and the width of the contact at the end of the contact arm. Note also that these effective contact gaps are likely to vary with the state of wear and cleanliness of the contacts.

The second disadvantage is also related to the inertia of the load on the training drive: which, since it consisted of a 9-foot rangefinder and its operator, was considerable. If the mounting slewed off the correct bearing, it had to be driven back by the action of one of the clutches. Although the clutch would disconnect once the correct bearing was reached, the inertia of the mounting tended to carry it past this position. Thus the contact

[4] 'Pollen Aim Corrector' (*op. cit.*).

arm would make contact with the opposite segment of the arc, thereby energising the other clutch. This would reverse the direction of rotation and drive the inner tube back towards the correct position. However, there was a danger that the clutches would continue to be energised alternatively, resulting in the inner tube 'hunting' to and fro about the correct bearing.

The *Ariadne* design used two means to counter these effects. Firstly, a rotation of 30° by the armature plate produced a change of only 1/40° in the training of the rangefinder i.e. the reduction gear ratio was 1,200:1. Secondly, a spring coupling was inserted between the armature-plate shaft and the drive shaft to the mounting;[5] the latter shaft was also fitted with a pair of fly-wheels, one connected rigidly, the other through a friction coupling. The whole assembly was intended to smooth out the jerky movement of the armature. However, the resilience of the spring connected to the load inertias created a coupling with a natural frequency of mechanical oscillation: though any oscillations would have been damped by friction in the high-ratio gearing and, possibly, in the fly-wheel coupling.

Either hunting by the 'bang-bang' servo, or oscillations in the flexible coupling, or a combination of the two, would explain the 'rhythmical motion' which had to be countered by the rangefinder operator.

4. BEARINGS TRANSMITTED FROM THE RANGEFINDERS

In the mountings fitted with the air-driven dual or single gyros, the gyro reference had to be clamped parallel to the keel while the ship turned. The servo which controlled the training of the inner tube of the mounting then held its bearing on the keel-line.

Once the ship had settled on a new course, the gyro reference was released at the moment when the keel lay on the mean-course line. The servo action then held the inner tube of the mounting on the mean-course line, even though the ship might be yawing. Thus, if the rangefinder was trained on the target by rotating the outer tube relative to the inner, the angle between the two tubes equalled β, the target bearing relative to mean course. Hence the rotation of the bearing transmitter was controlled by the rotation of the outer tube relative to the inner.

[5] The divided arc was connected directly to the armature shaft, the best configuration for an intermittent drive: P L Taylor, *Servomechanisms* (London, 1960) pp.198-9.

If the ship altered course, the gyro reference was again clamped parallel to the keel. Once a new mean course was established and the rangefinder trained on the target, the transmitted angle was again the target angle relative to mean-course.

When the *Natal* table was modified in the attempt to plot true course, it was fitted with its own gyro reference so that it could plot own course correctly relative to True North. To plot enemy course, the enemy plotting arm had to be positioned according to the angle between own instantaneous course and target bearing.[6] Thus the bearing transmitter must have been reconnected so that it transmitted the angle between the outer tube and the pedestal. The inner tube was otherwise unaltered; the gyro reference in the mounting could then still be used to assist the rangefinder operator in training, though only while on a steady course.

In the final production Argo mountings, the Argo gyro was replaced by an Anschütz gyro compass receiver. This provided a directional reference to True North irrespective of course changes. Thus, by the action of the training servo, the inner tube could be held at all times in alignment with True North. For true-course plotting, the mounting was still required to transmit the angle between the outer tube and the pedestal. In contrast, for dual-rate plotting, the mounting had to transmit target compass bearing. This meant reverting to the arrangement whereby the transmitter transmitted the angle between the inner and outer tubes. This could also be used for dual-rate plotting with the older Argo air-driven gyro. While own course was steady, it did not matter whether the transmitted bearing angle was relative to True North or to mean-course; the slope of the bearing plot equalled the rate of change of compass bearing in both cases.

5. THE *NATAL* STRAIGHT-COURSE PLOTTER

Patent 5,031 of 2 March 1909 described a manual plotter, which was probably the same as the plotters in the second batch supplied by Pollen in 1909 to naval acquaintances (Plate 11). Its basis was a large board, to which the plotting paper was pinned, with a bar mounted across the centre. A carriage was moved along the bar by a threaded rod rotating at one of a selection of fixed speeds determined by interchangeable discs.[7] The carriage carried both the pen plotting own ship's course: and the range bar

[6] Patent 1,111 applied for 15 January 1910, complete specification 12 August 1910.

[7] A constant speed of rotation was maintained by reference to the seconds hand of a stop-watch: patent 25,654/1908, applied for 27 November by Isherwood. This unimportant patent is unique in not being taken out jointly with Pollen.

used to plot the enemy course. The bar was provided with angular scales so that it would be set at the correct angle relative to own ship's mean course, which was parallel to the bar and threaded rod. The patent also described manual procedures for plotting through a turn, but these are of doubtful practicality and accuracy; they depended on unpinning the paper from the board, inserting a pin a distance from the course line equal to the radius of turn, and then rotating the paper through the angle of turn, meanwhile manipulating the target range-and-bearing bar as the target bearing changed.[8]

This patent is the best guide to the general layout and principles of operation of the automatic straight-course table which was delivered to the *Natal* in September 1909. Unfortunately, no detailed description has survived, although Pollen himself confirmed that 'the paper on which the chart was made was pinned upon the plotting table, and the plotting pen traversed over it'.[9] However, some of its features can be inferred from Pollen's and Isherwood's next plotter patent, 1,111 of 1910.

The provisional specification applied for on 15 January, describes, but only in outline, several different designs for a true-course plotter; its purpose was clearly to claim as broadly as possible while an actual design was still being worked out. One design was in effect an automatic version of the manual scheme described in 5,031/1909: but it was not used to modify the *Natal* table for true-course plotting. Instead of traversing the pen which plotted own ship's course, it was held stationary in the middle of the table; the plotting paper was pinned to a wooden board, which was moved (linearly and in rotation) by the action of the two pricker wheels located beneath the pen. This method of driving the paper proved wholly impractical. However, the same principle was retained for the complete specification of 12 August 1910; the wheels below the paper now drove it directly through rubber rims, firm contact pressure being maintained by a matching pair of pressure wheels mounted above the paper.

Unusually, the complete patent specification is quite different from the provisional, both in text and drawings (Plate 14). Nonetheless, the new design retained features which suggest that it was derived from an earlier table in which the carriage carrying the plotting pens moved. Like the earlier manual plotter, the carriage is mounted on transverse bars (though two rather than one): while its original direction of movement is still shown as small arrows on the top! Similarly, the arrangement of drive shafts to

[8] Patent 5,031/1909 applied for 2 March, complete specification 13 September.
[9] *PP*, 'The Quest for a Rate Finder', November 1910, p. 264.

operate the target range-and-bearing arm would have worked equally well with a moving as with a fixed carriage. Thus it seems probable that these later drawings give a good indication of the general layout of the earlier straight-course table.

6. ARGO CLOCK MARK I

The first Argo clock generated a 'simulacrum' of virtual course. Its general arrangement is shown in Plate 15, which is taken from patent 360 applied for on 5 January 1911. The instrument was approximately two feet square,[10] with the target range and bearing hands pivoted at its centre. This centre represented own ship, while the target was represented by a moving cross-piece P. Two long rods at right angles ran through the cross-piece, so that it was constrained always to lie at their intersection. The horizontal rod was attached to a split nut around a vertical screw: while the vertical rod was similarly connected to a horizontal screw. As a result of the vertical and horizontal displacements caused by the rotation of the two screws, P moved relative to the centre of the clock at a speed and in a direction corresponding to virtual speed.

The design depended on the assumption that own course was parallel to the horizontal screw. Thus the vertical screw had to move P at a speed proportional to the component of the virtual speed perpendicular to own course (v_y). This component derived solely from the perpendicular component of enemy speed i.e.

$$v_y = e \sin\theta$$

The horizontal component of virtual speed (v_x) was derived from own speed subtracted from the horizontal component of enemy speed:

$$v_x = e \cos\theta - s$$

In the mechanisms shown at the bottom of the diagram, a rotating disc was set by the right-hand knob to the angle between courses, θ. The disc carried two pins separated by a right angle; the pins displaced two sliding links by amounts proportional to $\cos\theta$ and $\sin\theta$. Two proportional levers multiplied these two displacements by the enemy speed e set on the adjacent knob. The resultant displacement proportional to $e \sin\theta$ was used directly to control the position of the ball in one of two variable-speed drives;[11] this

[10] Argo Company, 'The A.C. Range and Bearing Clock, Mark II' p.2 with I E Brown, Secretary, Argo Company to the Secretary of the Admiralty, 15 May 1911 in RCAI Claims Files for Argo Co. and A H Pollen, T.173/91 Part III, PRO. In the Mark I clock, one thousand yards was represented by 6 inches.

[11] The variable speed drives were driven by a clock-regulated constant speed electric motor as patented in 9,223/1909.

drive then rotated the vertical screw at a speed proportional to v_y. The ball of the second drive, which was connected to the horizontal screw, was positioned by subtracting a displacement proportional to own-speed s (set on the left-hand knob) from the displacement proportional to e $\cos\theta$.

The cross-piece P was coupled to a frame G pivoted at the centre of the clock; the angle of the frame directly indicated the bearing angle from own course; an endless chain within the frame, which was coupled to a sprocket wheel connected to the range hand, ensured that the indicated range was proportional to the distance from the centre to the cross-piece. The *Natal* clock also had a second frame, likewise coupled to the cross piece, but its other end could be displaced from the centre of the clock by vertical and horizontal distances proportional to the two components of virtual speed multiplied by the time of flight.[12] Thus two additional hands operated through this frame indicated gun range and gun bearing.[13] Although the details have not been found, the clock was able to transmit gun range and deflection (so there must have been a differential of some sort to derive deflection by subtracting the two bearings indicated on the clock). It was also possible to apply spotting corrections to the transmitted ranges and deflections.[14]

As in Hughes-Onslow's essay, the patent claimed that the settings of the control knobs could be altered while the clock was running;[15] however, in practice it was found that the variable speed drives were 'not capable of driving while the speed was being altered'.[16] The patent also described how, before starting, the target range and bearing were set by releasing the split nuts on the vertical and horizontal screws; it also stated that if 'the ranges indicated by the clock begin to differ from those observed at the rangefinder...corrections should be made in the positions of the range and bearing hands'. However, the only method described for making such corrections was to disengage the split nuts on the driving screws i.e. in effect to stop the clock.[17]

As Hughes-Onslow recognised, if own ship altered course (and assuming that the enemy did not), this produced an equal and opposite effect on the angle between courses, which could be set on the right-hand knob i.e. from Fig. 2.11:

[12] Time of flight was set on the second knob from the left.
[13] This feature 'did affect the accuracy of the clock', though the extent was not stated: 'A.C. Clock Mark II' (*op. cit.*) p.14.
[14] Report by Lieutenant R Plunkett, *Natal*, 4 July 1910 in DRAX 3/3.
[15] Patent 360/1911 applied for 5 January (identical complete specification 28 June), p.2.
[16] Argo Company, 'Memorandum', 6 May 1913 in T.173/91 Part II.
[17] Patent 360 /1911 (*op. cit.*); see also *PP*, Pollen to Admiral Colville, 1 July 1910, p.249.

$$\lambda = \theta + \kappa$$

and, if $\delta\lambda = 0$ (steady target course)

$$\delta\theta = -\delta\kappa$$

However, since:

$$\chi = \beta + \kappa$$

$$\delta\beta = \delta\chi - \delta\kappa$$

There was no means of applying the large change in β due to the change in course $\delta\kappa$ except by stopping the clock and releasing the split nuts on the vertical and horizontal screws. Thus the Mark I clock was fundamentally incapable of keeping the bearing during a turn by own ship; it was not helm-free.

> The Argo Clock Mark I could not...compute ranges and bearings accurately while the firing ship was turning, because its mechanism was incapable of integrating the turning motion of the firing ship with the straight motion of the target to produce the virtual replication of relative motion that was required.[18]

More precisely, the mechanism was incapable of integrating during a turn because the variable-speed drives stopped driving the mechanism if their speeds were altered. Even if this had not been the case, the clock could not have computed ranges and bearings because the target bearing could not be altered in accordance with the change of course. Furthermore, the schematic diagram on p.209 of *In Defence of Naval Supremacy* seems to imply that the clock contained a mechanism analogous to a Dumaresq. In fact, there was no 'trigonometric calculating mechanism' which, when set with a range-rate and a bearing-rate, firing ship speed and target bearing, generated target course and speed. Indeed, there were no displacements anywhere in the clock which, in the general case, were proportional to the range and bearing rates.

The idea that the clock had separate means for setting rates probably arose from correspondence after the *Natal* trials.[19] The Admiralty had insisted that any future clock must 'be capable of being set for rate alone in addition to the existing means of setting'; this would have allowed it to be used like a Vickers clock with a range-rate obtained from a rate-plot or a Dumaresq. Pollen replied that:

> The clock in its present form is not only "capable of being set by rate alone in addition to other means of setting", but what seemed adequate instructions for so setting it are in fact engraved on the dial provided for the purpose.[20]

[18] Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) p.208.
[19] The letters are cited in *IDNS* (*ibid.*) p.205.
[20] Secretary of the Admiralty to Argo, 19 August 1910 and Pollen to Secretary 25 August 1910 in

This rate dial was mentioned during the second of the RCAI hearings.

> MR. ISHERWOOD: There is a small dial...which says rate of change in yards per minute and by setting these dials to zero I can now set on here any rate....
>
> MR. MORITZ: It becomes a Vickers clock?
>
> MR. ISHERWOOD: Yes, exactly.[21]

Isherwood also confirmed that one of the dials set to zero was target course. Thus the most likely procedure was that subsequently described in the provisional patent specification for a quite different clock mechanism, the Argo Clock Mark II; however, the fundamentals were no different.

> ...it is possible to set up the rate of change of range directly in the machine by setting bearing, target course, and target speed to zero, and setting up rate of change of range by the ship's speed handle...[22]

The Mark I clock may have had a separate range-rate dial coupled to the own-speed handle: or perhaps the own-speed dial may have been calibrated in both knots and yards per minute. Note that the settings described in the last quote correspond to own ship steaming directly towards a stationary target, so they would only have worked satisfactorily if the rate was negative. If a positive rate was required, the enemy bearing could have been set to 180°.

Thus the Mark I clock could be set for rate alone if all that was required was to work it like a Vickers clock. However, it could not be set for range and bearing rates like the later Argo clocks.

7. ARGO STEP BY STEP TRANMISSION GEAR

The patent for the Argo step-by-step transmitting gear was applied for on 24 March 1911; the provisional specification stated that it was intended 'for use in operating charting tables', though this was omitted form the complete specification. As in other step-by-step systems, the transmitter was very simple (see Plate 17); in the Argo design, the transmitter shaft revolved a wiper arm over three stud contacts; thus only four wires were needed to connect transmitter and receiver. Just like the first rangefinder mountings (though presumably on a smaller scale), each receiver used a pair of magnetic clutches to drive its part of the plotter, so there was plenty of driving torque available. The clutch

T.173/91 Part VII.

[21] RCAI Minutes of Proceedings, T.173/547 Part 11. Moritz was Counsel for the Crown

[22] Provisional Specification for patent 19,627, 4 September 1911, p.10 in T.173/91 Part III.

windings were connected through slip rings to a revolving drum; the drum was geared to the output shaft driven by the armature plate 3 mounted between the clutches. Three sprung contacts were disposed around the drum, each drum contact being connected to a corresponding stud contact at the transmitter. The pattern of the two conducting sectors (6 and 7 in the figures) on the surface of the insulating drum were such that each drum contact touched at most one sector; if the corresponding transmitter contact was at the same time under the wiper arm, electric current was conveyed through both contacts and the slip rings to a clutch. While the clutch was energised, the armature plate was attracted to its surface and the output shaft revolved.

The conducting sectors on the drum were configured so that, around the circle traced by the contacts, there was one wide and one narrow gap. Assume, as in the figures, that the wiper arm lay on transmitter contact A′. If the wide gap was not already under drum contact A, A would make a connection through one of the drum sectors to a clutch winding; the wiring was arranged so that the clutch rotated the drum in the direction necessary to bring the gap under contact A. The power would then be disconnected from the clutch and the drive shaft would stop turning. If the transmitter arm then moved on to (say) contact B′, the appropriate clutch would be energised through sector 7 so that the drum would rotate clockwise until the gap lay under drum contact B.[23]

The clutches were driven continuously at one speed. When a clutch was first energised, the armature plate was attracted to its friction disc; due mainly to the inertias of the plate and the mechanical load, the plate would slip on the clutch disc while it accelerated towards the speed of the clutch. When the clutch released, the same inertia would keep the plate and load rotating until brought to a halt by friction. If the inertia was high and friction low, the gap on the receiver drum could overshoot the contact, resulting in the other clutch being energised. This would reverse the direction of rotation of the armature plate and bring the gap back towards the contact; if the ratio of inertia to friction was unfavourable, the cycle could repeat several times, the output shaft hunting back and forth before eventually settling. A simple plotting pen driven by a long screw, as used in the Argo rate plotter, should not have had this characteristic, but the inertial loads imposed by the complex carriage and large chart of the true-course plotter could have been significant.

[23] Patent 7,383/1911, applied for 24 March, complete 25 September.

If the transmitter turned slowly, the receiver moved in a series of jerks, each of one third of a turn. At the other extreme, the receiver could never rotate faster than the clutches: so a rapid movement of the transmitter could result in the receiver getting out of step by one or more whole revolutions. The *Orion* trials found that:

> The transmission of ranges is on the Step-by-Step principle...If the working head [of the rangefinder] is moved too fast...the receiver will get out of step. To prevent this the working head is geared down [but] this is...very inconvenient for the range taker who likes to move the working head quickly to and fro before obtaining the "cut".

Clearly, the first essential was to ensure that the clutches rotated faster than the equivalent maximum speed of the transmitter; however, increasing the clutch speed would prolong the slipping when the clutch engaged and increase the tendency for overshoot and hunting when the clutch released. Another possible improvement might have been to increase the angular size of the transmitter contacts; with the small contact studs shown in the patent, the clutches would have been energised for less than a quarter of the interval between steps (assuming the transmitter was rotating at uniform speed). The behaviour of this transmission system at all transmitter speeds was dependent on complex interrelations between load inertia and friction, the inertias of armature plate and clutches, the characteristics of the clutch friction disc, the rotational speed of the clutches and the widths of the contact gaps at transmitter and receiver. Further, some of these factors were difficult to control and keep constant over time, notably the clutch friction and contact gaps. It is not surprising that, in service, the Argo step-by-step transmission system was troublesome at times.

8. THE SLIPLESS DRIVE

The Argo variable-speed drive should be regarded as Isherwood's engineering masterpiece. Earlier designs employed in the *Natal* plotter and the Mark I clock had used a disc, ball and two fixed rollers, but the ball had to be dragged sideways against the friction at its points of contact with the disc and both rollers. Isherwood now mounted the rollers in a carriage, which was arranged to slide (on ball bearings) parallel to the roller axes and a diameter of the disc (see Plate 20).[24] As before, the ball moved along the diameter, its distance from the centre determining the rate of rotation of the rollers and of the output shaft from the drive. But now the ball could be rolled along the diameter by the

[24] The essential features of the variable speed drive were first described in 'A.C. Range and Bearing Clock Mark II', pp.10-11 and 15-6, in May 1911.

rollers sliding in their carriage. Two decisive benefits were obtained. Firstly, the rate could be changed with minimal force; only rolling friction (of the ball itself and the ball-bearings supporting the carriage) had to be overcome at the surfaces subjected to the assembly force between disc and ball. Secondly, even when the ball was moving diametrically (the output rate of rotation was changing), it remained in rolling contact with the disc. Unlike a simple disc-and-roller variable speed drive, the ball did not slide on the disc when the rate was changed, so no errors (proportional to the torque load on the output and the distance moved by the wheel) resulted.

> ...owing to the changes in the ball's position being produced by a rolling action, the ball does not slip or fail to drive the rollers at the moment when its position is being changed.[25]

Two minor qualifications are necessary. Firstly, imagine the ball in the very centre of the disc i.e. the rate at zero, so the rollers do not rotate. The ball cannot rotate about a vertical axis because it is prevented from doing so by the friction between itself and the rollers. Thus, as the disc rotates beneath it, there must be rotary sliding in the minute area of contact between ball and disc. This sliding did not result in any slip-induced errors when the ball was exactly in the centre of the disc. However, when the ball moved slightly off centre and began to rotate slowly, the constraining effect of the rollers forced the microscopic surface features of the ball in the area of contact to follow straight (tangential) lines: whereas the surface features on the disc were moving in circular paths of small radius. Thus, while the ball was very close to the centre, there was still microscopic sliding in the area of contact. As the ball moved further from the centre, the curvature of the circular paths followed by the disc's surface features was reduced, until pure rolling contact was established.

Any slippage between ball and disc due to this effect only occurred when the ball was very close to the centre; since the rate was small, so too were any resulting errors. Later experience with disc and ball drives showed that the main disadvantage of this effect was that, at the centre, the sliding induced significant wear of the disc surface. Where possible in inter-War British fire control tables, the Argo-type drives were arranged to reduce the probability of the ball working in the centre of the disc.[26] In American Ford

[25] Provisional specification for the Argo clock, patent 19,627 applied for 4 September 1911, p.2, T.173/91 Part III. The same words are used in the patent for the Argo variable-speed drive, 17,441 applied for 12 April 1912.

[26] See for example the 'disc-and-ball generators' in the Speed Across Plotter Unit of the AFCT Mark IV*: Admiralty, Gunnery Branch, *Addendum No. 2, Handbook for Admiralty Fire Control Tables, Marks IV and IV*,*

fire control tables (which used a variable-speed drive with two balls and a single roller), the higher-power 5-inch variable speed drive was designed to allow the ball in contact with the disc to rotate about the vertical as well as the normal horizontal axis: even though this design appears to have required a greater force to move the balls as the rate changed.[27]

Secondly, although a change of rate induced only rolling at the ball and ball-bearings, sliding friction had to be overcome between the moving rollers and their stationary shafts. The contact surfaces were not subjected to any assembly forces. However, a significant load on the output shaft would increase the sliding friction between the slot and key conveying the drive from the roller to the shaft. The Ford-type variable speed drive had the (probably small) advantage that its roller was stationary and the force required to move the balls was independent of the output load. The Ford design was also more compact, since the whole drive was little larger than the disc.[28]

9. RATE GENERATION IN THE ARGO CLOCKS

Dumaresqs

The fore-and-aft bar of the standard Dumaresq (see Chapter 3) was fixed parallel to the ship's keel, while the graduated bearing plate was rotated until its arrow pointed at the target. The angular scale around the circumference indicated target bearing against a pointer at the bow end of the fore-and-aft bar. The fore-and-aft bar was slotted from the centre half way to the after edge of the dial; in the slot, a sliding block was positioned at a distance from the centre of the dial proportional to own ship's speed. Beneath the first block, a second rotated on a pivot. The second block engaged with the slotted bar representing the target ship. A pointer on the bow of the target bar indicated the rates on the bearing dial graduations; the distance from this pointer to the pivot was set to be proportional to target speed.

1933, Book I - Text, pp.10-12 (ADM 186/275) and *Book II - Plates*, Plate 37A (ADM 186/276), PRO.

[27] Ford Instrument Co. for the Bureau of Ordnance, U S Navy, *Ordnance Pamphlet 1140, Basic Fire Control Mechanisms*, September 1944, pp.128-9. The author is especially grateful to Professor Sumida for a copy of this invaluable reference of over 400 pages.

[28] These considerations may explain why Ford-type variable-speed drives were preferred for the Admiralty Fire Control Clocks (AFCCs) and the Admiralty Fire Control Tables (AFCTs) Mark V and VI. For a technical study of these devices, see Allan Bromley, *British Mechanical Gunnery Computers of World War II* (Sydney, Australia, 1984).

The Turret Dumaresq differed in that the bearing dial was fixed in the turret with its arrow parallel to the guns. The fore-and-aft bar was rotated to lie parallel with the keel.[29] This form of the instrument was the most convenient for use in automatic clocks; because the bearing dial was fixed, the displacements of the target bow (or its equivalent) along and at right angles to the line-of-bearing could be taken off by links constrained to slide in fixed ways.

Argo Clock Mark II

The Mark II clock was not built but its description dating from May 1911 contains Argo's first intentions for a rate-generating mechanism. The figures are no longer attached to the copy in the PRO, but the essential elements are described clearly in the surviving text.[30]

The bearing dial and fore-and-aft bar were combined in a single, large, rotating disc. A scale for target bearings was engraved round the circumference of the disc; the target bearing was indicated by a pointer on the fixed body of the clock. A 'radial slot' cut in the disc extended from the centre half way to the circumference. A 'sliding piece' was positioned in the slot at a distance from the centre proportional to own speed. This piece carried a pivot for a second, smaller disc, the circumference of which was marked with a scale of target course. This smaller disc was also slotted and, in the slot, an 'adjustable piece' was located at a distance from the pivot proportional to target speed. From this adjustable piece, a stud engaged with a slot in a T-shaped link connected directly to the slide which determined the rate of the variable-speed drive generating the range.

As in subsequent designs, rack-and-pinion mechanisms were used to position the two sliding pieces.

Provisional Clock Patent Specification

The patent was applied for on 4 September 1911. It was accompanied by only a schematic diagram of the mechanism for generating range-rate. Although described as 'purely diagrammatic', this figure (Plate 21) and the text show that the design was still evolving.[31]

The mechanism was still based on a large, slotted bearing dial, the slot containing a sliding piece. A square plate was carried (but did not rotate) on this sliding

[29] Admiralty, Gunnery Branch, *Manual of Gunnery (Volume III) for Hios Majesty's Fleet 1915*, p.174, AL.
[30] 'A C. Clock Mark II'.
[31] 19,627/1911, Provisional Specification (*op. cit.*).

piece. The sliding piece also provided the pivot for a smaller dial, now called the 'target course dial', beneath which was fixed a bar 'or equivalent'. A piece sliding on the bar was positioned from the pivot at a distance proportional to target speed; this sliding piece carried a pin engaging with the slotted, T-shaped link to the variable-speed drive. The target dial rotated above the square plate; the main purpose of the latter appears to have been to carry the pointer which indicated the target course on small dial.

Complete Clock Patent Specification

The complete specification of 4 April 1912 was accompanied by detailed mechanical design drawings.[32] These were used unchanged in the American patents, from which Plate 23 is taken;[33] however, the drawings do not show the rate mechanisms clearly and the following description is based on the text.

In the final design, the rotating and sliding pieces are all placed underneath the main bearing dial. This dial was still calibrated to indicate target bearing; it also carried the additional knobs and dials for setting and indicating target course and own and target speed.

Beneath the bearing dial, a 'rotating slide or way' turned about its centre. In the slide, a block was positioned at a distance from the centre proportional to own speed. The block carried a 'vertical tubular member', about which rotated a second slide, in which a second block was positioned at a distance from the pivot proportional to target speed. The angle of the second slide was set according to target course. The second block carried a pin which determined the position of the slides of the variable-speed drives which integrated the speeds along and across.

Thus, the initial attempts to use slotted dials were abandoned. In the final clock design, the own-ship slide was like a shortened version of the Dumaresq's fore-and-aft bar. In both clock and Dumaresq, the first sliding block provided a centre of rotation for the member representing target course. In the clock, this was the target slide, while the enemy bow was represented by the second sliding block with its pin. In a Dumaresq, the second block pivoted on the first; this enabled the target bar to both rotate and slide, so that its bow pointer corresponded functionally to the clock pin.

[32] Complete Specification of patent 19,627/1911, 4 April 1912 in T.173/91 Part III.
[33] U S Patent 1,162,510, 30 November 1915 (application 788,266 filed 5 September 1913).

10. ARGO CLOCK MARK III

The mechanism of the Argo Clock Mark III (the design as patented) was housed within a rectangular enclosure with dials arranged on top, the Dumaresq to the right and the large, spiral range scale to the left. The fixed axis in the clock representing the line-of-bearing lay along the diameter of the Dumaresq dial which ran through the bearing pointer (Plate 22) . The clock contained four Argo-pattern variable-speed drives, labelled I-IV in the drawings, enabling the clock to generate both the range and bearing of the target (Plate 23 and Fig. 4.2).

Drive I integrated speed-along to give change of range; it was located beneath the Dumaresq, with its rollers parallel to the line-of-bearing. The target bow pin (see the previous note) engaged directly with a slotted plate fixed on top of the roller carriage, thereby setting the range-rate.

Target bearings were generated by Drives II and III, which were mounted to the left of Drive I, with their roller axes perpendicular to the line-of-bearing; this allowed one roller in each drive to be coupled together by a short straight shaft. The carriage of Drive II bore a plate with a slot which also engaged with the target bow pin protruding downwards from the Dumaresq linkage. Thus the rollers of this drive rotated at a speed proportional to speed across. Drive III worked 'in reverse'; instead of the disc being the driven member, one of its rollers was driven by the shaft from Drive II. The carriage of Drive III was positioned by a screw driven from the output of Drive I. The mechanical design was such that the distance of the ball of Drive III from the centre of its disc was proportional to the range generated by Drive I. Let θ represent the angular position of the shaft joining the rollers of Drives II and III. Then, from the equations given for a variable-speed drive in Fig. 3.1 and for speed-across x in 2:4:

$$\frac{d\theta}{dt} \propto x \propto R\frac{d\beta}{dt} \qquad \text{assuming a steady course.}$$

Because the ball of Drive III is positioned such that $r \propto R$

$$\frac{d\theta}{dt} \propto R\frac{d\phi}{dt} \propto R\frac{d\beta}{dt}$$

where ϕ represents the angular position of the disc of Drive III. Therefore:

$$\frac{d\phi}{dt} \propto \frac{d\beta}{dt}$$

and: $$\phi_2 - \phi_1 \propto \beta_2 - \beta_1$$

Thus, by coupling the disc of Drive III to the bearing dial of the Dumaresq, the slides representing own and target course were rotated at the correct speed relative to the line-of-bearing. Hence the speeds along and across were correctly maintained. In the opinion of Professor C V Boys:

> Perfect as the integrators are as an element in the design of the "Clock" the manner in which they are cross connected so as to provide a constant mechanical solution of the ever varying triangle of velocity is equally so, and the conception and execution of the "Clock" as a whole represents in my opinion the high water mark of invention in this field.

With justification, he acknowledged Isherwood's 'genius'.[34]

The Mark III clock was provided with two scales for displaying the current rates of range and bearing, and with two knurled knobs for setting the rates.[35] Thus the Dumaresq was reversible. It could be set for target course and speed and indicate the resultant rates: or it could be set with rates (or the rates could be corrected from rate plots or by spotting for range rate and deflection) and the target speed and course would be set or adjusted automatically. Note that, since the clock had no scale showing deflection in knots, any deflection corrections had to be converted by some means into bearing rate at the range in use.[36] At the front of the clock, two handles were used to set or correct the indicated true range and the target bearing relative to own course. These handles operated clutches which disconnected the variable speed drives while the clock readings were being altered manually.

The control lever below and to the right of the Dumaresq dial was left in the 'STEADY' position until the course was altered, when it had to be moved to 'TURNING'. When the lever was in this position, the bearing dial was disconnected from Drive III and the target bearing was set by hand, using the right-hand handle. During the turn, the target course dial was clamped relative to the line-of-bearing i.e. the inclination was held constant, so it was only approximately correct after the turn.

[34] Boys to Pollen, n.d. but 1912 in T.173/91 Part II.

[35] Fig. 5 of the complete specification shows an additional scale surrounding the range-rate knob; its purpose appears to have been to indicate the latest change in range-rate, in which case its pointer (while disconnected from the rest of the mechanism) would have been returned to zero between one change and the next. However, the scale and pointer are neither shown on the other drawings nor mentioned in the text; they appear to have been late additions to the patent and, since they were not present in the Mark IV, were probably not fitted to the *Orion* clock.

[36] It is not known how this correction was made. To avoid having to make calculations under the stress of battle, some form of graphical or tabular method was probably used.

The range scale of the Argo clocks was a spiral, so that the range indicated by the pointers could be read easily to the nearest 50 yards up to 20,000 yards.[37] The first pointer, labelled RANGE FINDER, was coupled through the clutch to Drive I; the clock was correctly set when this pointer followed the mean of the ranges received from the rangefinder. The second pointer showed GUN RANGE; it was connected to and moved with the first, but could be offset by an amount equal to the total spotting correction. The patent indicates that spotting corrections were set using a knob in the centre of the range dial. Two spotting scales are shown on the plan view in the patent, but only one in the elevation, while neither scale is mentioned in the text. Sumida cites a letter from Pollen to the DNO, dated 17 April, indicating a four to six weeks delay in availability of the clock if it were to be fitted with a spotting pointer;[38] thus it appears that the arrangements for setting spotting corrections were added to the patent's Complete Specification at the last moment.

The GUN RANGE pointer indicated the range which had to be transmitted to the follow-the-pointer sights. This aspect of the design, which had previously been dismissed as a mere engineering detail, was actually a major difficulty which, the surviving documents suggest, was never entirely resolved. The designers were faced with three problems. Firstly, the follow-the-pointer transmitters and receivers were step-by-step: that is, irrespective of gun range or elevation, one step always produced a constant angular movement at the receiver. However, the range scales of the gun-sights, which determined the gun elevation, were non-uniform: which is to say that, at different ranges, the same change in range required different angular movements of the range pointer. This meant that, at different ranges, the same rate of change of range required that the transmitters be driven at different rotational rates. Secondly, the gun sights had several different range scales to allow for firings with full and three-quarter charges as well as 6-pr. rounds.[39] The third problem was that, if the clock was to transmit automatically, it had to develop sufficient torque to rotate a number of transmitters without interfering with its operation as a range and bearing integrator.

The Argo Clock Mark III tackled the third problem by driving the transmitters with a fourth variable speed drive (numbered IV). The position of the carriage of this

[37] As the pointers revolved, their length changed automatically in order to follow the spiral.
[38] *IDNS*, p.222.
[39] In turrets, these were fired from aiming tubes fitted inside the bores of the guns: Viscount Hythe (ed.) *The Naval Annual 1913* (Newton Abbott, reprinted 1970), p.328.

drive (and hence the rate at which it turned the range transmitters) was controlled by a lever with a moveable pivot. The other end of the lever was connected directly to the carriage of Drive I, while the position of the pivot was controlled by a spiral cam which was connected through shafts and gears to the RANGE FINDER pointer. The effect of this mechanism was that, at any particular range, the transmitter rate was proportional to the range rate: while the action of the cam ensured that, as required, the ratio of range rate to transmitter rate could alter as the range changed. However, there were three objections to the design. The first was that nothing in the description of the Mark III clock (or, indeed, of the later marks) suggests that the cam could be changed to allow for the different gun range scales. Secondly, since the transmitting arrangements were concerned with gun range, the spiral cam which altered the transmitter rate should have been connected to the GUN RANGE pointer, not the RANGE FINDER pointer. However, the third objection was fundamental. The output from Drive IV was entirely unaffected by range corrections, whether spotting corrections (which moved only the GUN RANGE pointer) or range corrections set using the handle (which moved both pointers together).

As explained in Note 12, these design errors were corrected in the Mark IV clock, though the solution was not automatic and required an additional operator to follow a pointer. It is uncertain how far the *Orion* clock had been modified by the time of the trial held in November 1912. Afterwards, two functions 'which might be automatic and are not so' were described as 'watching the transmission dial to the sights' and 'putting spotting corrections on transmission dial'.[40] These operations were still necessary with the Mark IV clock, so the *Orion* clock may already have been fully altered. Alternatively, it is possible that only part of the full Mark IV solution was adopted for the Mark III, such that Drive IV drove a follow-the-pointer step-by-step transmitter through a slip coupling.[41] Spotting corrections would then have been put only on the transmitted range, not on the clock; however, if it became necessary to tune the clock's rangefinder-range, the change would not have been transmitted unless the same correction was also applied as a spotting correction.

[40] F C Dreyer and C V Usborne, *Pollen Aim Correction System Part I. Technical History and Technical Comparison with Commander F.C. Dreyer's Fire Control System*, February 1913, p.38, AL.
[41] A differential would have been better mechanically, but the Mark IV used a slip coupling.

II. THE *ORION* TRIALS

The Mark III clock was installed aboard *Orion*, probably in early September 1912. Pollen had visited the ship just before 20 September, while Argo engineers were then allowed on board for the pre-trial experiments, which took place from 23 to 25 September and 30 September to 2 October. In one of these trials, the ship followed a course around a large rectangle while the clock was required to keep the range and bearing of a fixed mark. The range varied between 1,000 and 10,000 yards yet *Orion's* Captain recalled that, at the end of the circuit, the range was 'correct...within a small amount as far as I can remember' (Pollen claimed it was within 25 yards of the correct value).[42] This was clearly an excellent performance. Even so, it is not inconsistent with the approximations inherent in the Mark III design; because the target was stationary, it made no contributions to the speeds along and across, so it did not matter if the inclination was incorrect.

Further range-keeping exercises took place on 9 and 19 October, after which. *Orion* was involved in the director trials which culminated in the firing with *Thunderer* on 13 November. Then, on 19 and 20 November, *Orion* conducted two trial runs with the Argo clock, one with full charges, the other with three quarter charges.[43] In both, conditions were taxing. Each began after a large turn to bring the target dead ahead. The target altered course while ranges and bearings were still being taken. Then, after the clock had ceased to receive ranges and bearings, *Orion* herself turned away (by 30° in the full charge run, by 60° with ¾ changes) and only then opened fire. In the full charge run, the opening range was 9,600 yards while the initial rate error was 150 yds/min; two spotting corrections of 'Down 400' were needed before commencing the bracket. Further complication was introduced after two minutes' firing by reducing from 15 to 10 knots and commencing a long, slow turn of 67° in the next three minutes. The bracket was completed and the target found while still turning, during which 3 hits were made.

> When the ship was steadied the rate on the clock although not absolutely correct was sufficiently accurate to enable hits to be obtained...continuously throughout the rest of the run.

[42] *IDNS*, p.228. Rear Admiral Craig Waller before RCAI in T.173/547 Part 12, p.13.
[43] *IDNS*, p.231 and *Orion's* log in ADM 53/24312. The author is most grateful to Professor Sumida for a copy of his transcription of the log.

After steadying, hitting was aided by ranges and bearings again being made available at the clock and by a low rate (less than 200 yds/min). The rate of fire was slowed by two turret breakdowns but in all 14 hits were made from 40 rounds.

The run with 3/4 charges was less successful, partly because the opening range (9,600 yards) was much greater than planned (8,050 yards). Also, during the approach on opposite courses, the towing ship had obscured the target. No hits were made in the first period of firing. Then further ranges and bearings were made available for three minutes, after which both *Orion* and her target altered course outwards (by 90° and 30° respectively). Remarkably, when fire commenced after the turn,

> ...the second salvo straddled the target. The rate on the clock was approximately correct and hitting therefore continued for the remainder of the run...22 rounds were fired in 3'42" by the 3 after turrets...8 hits were obtained.[44]

Thus, in both runs the clock had proved capable of keeping range and rates through large turns. However, except during the approach to the full-charge run, the courses were either convergent or divergent and did not induce a high speed across; thus the true inclination changed little as *Orion* turned and the constant inclination maintained by the clock would not have introduced significant errors. The descriptions of the two runs both state that the clock received neither ranges nor bearings while *Orion* was turning. In that case, while the control lever was at 'TURNING', the change in target bearing can only have been set on the clock by using the change in own course as indicated by a gyro compass receiver. Again, because of the low speed-across, this would have been a good approximation to the change in target bearing.

12. ARGO CLOCK MARK IV

The Argo clock which finally saw service in the Royal Navy was known as the Mark IV; it was fully described in a handbook promulgated in January 1914.[45] This production model (Plate 24) differed significantly from the patented Mark III design. The most conspicuous external change was the addition of an extension on the right-hand side of the clock; this carried a Vickers follow-the-pointer range receiver (though with an extra red pointer as well as the usual black pointer), range transmitters and a range setting handle H4 (Plate 25). The range spotting scales and controls had been improved. Spotting

[44] 'Full Charge Run' and '3/4 Charge Run' in the Craig Waller Papers, courtesy Commander Michael Craig Waller (copies of transcriptions by Professor Sumida gratefully acknowledged).
[45] Gunnery Branch, *The Argo Range and Bearing Clock Mark IV*, January 1914, AL.

corrections were set using a handle H1 on the front of the clock; the total spotting correction (the difference between RANGE FINDER and GUN RANGE) was shown on a scale in the centre of the range dial. However, each spotting correction was set independently (with the handle H1) on the small SPOTTING scale at the top left of the clock: after which the scale could be reset to zero (using the button D) ready for the next correction. When H1 was turned, the GUN RANGE pointer was moved (through the action of a differential) to increase or decrease the total spotting correction by the amount set on the spotting scale. Thus spotting corrections could be set while the clock was running and the range rate was being applied to both range pointers. Like the Mark III, the handles H2 and H3, which altered RANGE FINDER range and target bearing respectively, worked through clutches which disconnected the variable speed drives.

Another addition to the dials on top of the clock was a small dial with a ship-shaped pointer indicating inclination. Hence the clock now gave a birds-eye view of own and enemy course relative to the line of target bearing. This dial and the new range spotting features were probably among the improvements added at the suggestion of naval gunnery experts. The Mark IV clock, like the Mark III, had scales and setting-knobs for range-rate and bearing-rate; but there was no sign of the additional scale for indicating change of range-rate. Respecting bearing rate, Usborne complained that the clock did not generate deflection;[46] of course it did (as speed across) but it did not display the value generated. Thus, as with the Mark III, it was necessary to convert spotting deflection corrections from knots into the equivalent degrees per minute before putting them on the clock.

Like the Mark III, the Mark IV clock retained the 'STEADY/TURNING' lever; thus, like its predecessor, while own ship turned, the clock was set by hand to target bearing; the easiest and most accurate method was to use the bearings received (on the digital receivers) from the Argo rangefinder mounting. However, due to a major internal redesign, the clock now correctly generated the change in inclination during a turn. Even when own course was changing, Drives II and III continued to integrate speed-across divided by range. Thus, if, as in the previous note, ϕ represents the angular position of the disc of Drive III and χ the target compass bearing, it follows from equation 2:9 that:

$$\frac{d\phi}{dt} \propto \frac{d\chi}{dt}$$

[46] *Technical Comparison* (*op. cit.*) p.61.

From Fig. 2.11:

$$\lambda = \iota + \chi$$ and, since λ (target compass course) is constant

$$\frac{d\iota}{dt} = -\frac{d\phi}{dt}$$

In the Mark IV, the effect of moving the course lever to TURNING was, as in the Mark III, to disconnect the bearing drive from the bearing dial so that the latter could be set by hand. However, the lever no longer clamped the target course dial stationary; instead, it caused the target course dial to be connected (in the correct rotational sense) to the disc of Drive III; thus the target inclination ι was correctly maintained through the turn. As its handbook now declared: 'The mechanical accuracy of the clock is practically perfect': provided, of course, that the target bearing and own speed were correctly set by hand throughout the turn.

Despite the mechanical accuracy of the clock, the arrangements for driving the electrical gun range transmitters were still imperfect. Drive IV and its spiral cam were retained, while the rollers of this variable speed drive were connected, through a slip coupling, to the step-by-step transmitter switches; the black N pointer of the sight dial on the side of the clock was driven by a step-by-step receiver wired to one of these transmitters. Thanks to the addition of a new differential to the Mark IV, the spiral cam now followed gun range rather than rangefinder range: but, as with the Mark III, the drive to the transmitters still could not register automatically any alterations to range set using H1 (spotting) or H2 (rangefinder range). The deficiency was overcome by introducing an additional operator to work handle H4. The shaft turning the spiral cam (which was coupled to the GUN RANGE pointer) was extended through the right hand side of the clock to a pair of specially-cut cams linked by steel bands. These cams converted the uniform rotation of the gun range shaft into a non-uniform rotation which corresponded to gun elevation. Through an intermediate gear-box, the cams drove the second, red M pointer on the range receiver dial.[47] This dial was graduated in the same non-uniform way as the gun-sights. Thus M indicated the correct gun-range on the receiver dial. If (say) a spotting correction was applied to the clock proper using H1, the M pointer would move by the correct amount: but the N pointer would not move at all.

[47] The gearbox ratios were selected by a lever with only two positions 'FULL & REDUCED' and '6 PDR'. This implies that war-service rounds fired with full charges had the same trajectories as practice rounds with reduced charges. The same assumption (which is not what might be expected) was not made in the transmitters fitted to the Dreyer tables, which had separate cams for full and reduced charges and sub-calibre firing: *Handbook of Captain F.C. Dreyer's Fire Control Tables, 1918*, p.72, AL.

At this point, the additional operator used the handle H4 to rotate the range transmitters, thus forcing a slippage in the coupling between the transmitters and Drive IV. The operator stopped turning H4 when the black N pointer (showing the range transmitted to the guns) coincided with the red M pointer, which showed clock-generated gun range. The net result was that, when the clock was correctly predicting gun range, the red and black pointers moved as one and no manual intervention was necessary: but that, if one or both clock range pointers were altered by the first operator using H1 or H2, the second operator had to work H4 to force the black pointer to follow the red. The design also had the advantage that, if there was slippage in Drive IV as it attempted to rotate the transmitter switches, the operator of H4 could make a correction.

Although inelegant, these transmission arrangements appear workable enough, although there were some problems in service. An undated memorandum from 1914 refers to 'slipping of the friction drive for the Red pointer viz. the pointer which indicates the gun range to be set on the sights'. The red (M) pointer, which was not enclosed, was carried on a hinged arm which would be rotated sideways out of the way of the range dial; the drive shaft within the arm incorporated a frictional coupling to prevent damage if any pressure was placed on the pointer. The memorandum also refers to 'back lash in the gearing': though it not stated what part of the clock was affected and, in any case, the problem had been rectified by Elliott Brothers.[48]

13. DATA FROM THE MARK IV TRUE COURSE PLOT

The true course plotter was constructed so that both pens drew small circles at time intervals of one minute along the plotted tracks of own and target ships. The plot of own course could be drawn as a continuous line, with the minute circles at intervals along it.[49]

Because the Argo power cut did not prove satisfactory when used with a coincidence rangefinder, the target course could only be plotted as a sequence of distinct points. To obtain accurate ranges, the operator first threw off his cut after taking a range; then he 'likes to move the working head quickly to and fro before obtaining a [new]

[48] 'Difficulties Experienced with "Argo" Range Clocks' in 'Important Questions dealt with by DNO', Vol. III, 1914, AL.

[49] For detailed descriptions of the mechanism of the Argo Plotter Mark IV, see patent 23,349 of 1912 (applied for 12 October, complete specification 11 April 1913). The description in the *Technical History and Comparison* pp.28-30 is very similar.

"cut" '.[50] Having made his cut, the rangetaker depressed a foot pedal, which caused the plotter to draw a new point on the plot of target course using the range and bearing transmitted simultaneously from the Argo mounting. Once the mounting had been provided with a separate trainer, it should have been possible to keep it bearing on the target almost continuously. Thus, at each minute, when the target pencil drew another minute circle in the vicinity of the target course, its bearing relative to the corresponding point on own ship's course would usually have been correct. However, the range could be seriously in error, especially if the rangetaker had just thrown off the cut. Thus, after plotting for a few minutes, the enemy course would have been appeared as an irregular line of course points intermixed with some more widely scattered minute circles.

To set the Argo clock, it was necessary to obtain from this plot:

the mean range of the moment

the target course

the target speed.

However, measuring off the plot was not easy, since it was moving continuously as the distance between the two pens fluctuated with the range transmitted from the Argo mounting. To assist with measurements, the plotter had a small straight scale revolving around the target pencil. This could be rotated to lie parallel with the mean target course, an operation which was possible even if the plot was moving to and fro along the line of bearing. Thus the process of measuring the target course would not have added much to the errors inherent in estimating the direction of the mean course line. Having set the scale, if the target course was more or less perpendicular to the line-of-bearing, a mean range of the moment could be obtained by waiting for the lateral movement of the plot to bring the mean course line directly under the scale line and immediately reading off the range from the Argo receiver. However, this method could not have been used if the target course was close to the line-of-bearing. The best estimate of the mean range would then have been the last plotted range: but, since this was not easily measured on the chart, it would have been necessary to keep a record of the ranges received.

To obtain the target speed, the distance travelled by the target in a known time interval was required. The minute marks were intended for this purpose; however, because of their wide scatter, no accurate value could be obtained simply by measuring

[50] *Technical Comparison*, p.34.

the distance between them. What was needed was not each minute-mark itself, but the point of intersection with the mean target course line of the instantaneous line-of-bearing at the moment that the minute-mark was drawn. In principle, if the plot was stopped, these points could be established by joining corresponding minute marks along the own and target courses. In practice, it was vital to keep plotting during the approach. This left only the alternative of trying to estimate the points of intersection by eye. This might not have been too imprecise if both ships were on similar courses: but when courses were in roughly opposite directions (the conditions of high bearing rate for which Pollen claimed his system was uniquely suited) such estimates would have been approximate at best. It would have been much easier and more accurate to ignore the minute circles and instead keep a record of the times of every plotted point on the enemy course. Then the distance between a selected pair of points could be taken off the plot with dividers and the speed calculated from the distance travelled in the interval between the two points.

No evidence has been found that the Argo system had an automatic method of recording the time and range of each plotted point: nor, indeed, that Pollen ever admitted that the minute circles were of little use. If they remained the only recommended method, Usborne was justified in stating:

> The A.C. cannot measure the enemy's speed accurately...[51]

14. ARGO CLOCK MARK V

The final Argo clock, the Mark V, was truly helm-free, incorporating a 'motor connected to the Gyro compass which automatically eliminates yaw and applies alterations of own ship's course'.[52] This part of the new design was described in outline in a provisional specification applied for on 9 May 1913: while full details, with drawings of the new Dumaresq, were left in the complete specification of 8 December (Plate 28).[53] The prototype was probably complete by mid-October; though the Admiralty declined an offer for a demonstration.[54] The principal external change, compared with the Mark IV, was the introduction of the compass scale which rotated as a ring outside the main bearing dial. As in the Mark IV, the fixed pointer (which established the fixed line in the

[51] *Technical Comparison*, p.61.
[52] Phillpotts Committee, 'Report of inspection at York of Pollen Fire Control System', n.d. but 1918, p.2 in DRYR 3/1, CC.
[53] British Patent 11,009/1913; also U S Patent 1,162,511 30 November 1915 (filed 14 April 1914).
[54] *IDNS*, p.247.

clock representing the line-of-bearing to the target) indicated on the bearing dial scale (now the inner scale) the target bearing relative to the keel-line. However, on the outer compass scale, it indicated target compass bearing. Consequently, the large arrow on the bearing dial (which represented own ship's keel) indicated own compass course on the compass scale.

Internally, the clock mechanism was still arranged to rotate a shaft at a speed proportional to the speed-across divided by the range. The equations in Note 12 demonstrate that this rotational rate is proportional to the rates of change in both inclination (ι) and target compass bearing (χ). Thus the shaft was coupled directly both to the compass scale and to the small dial which showed enemy course. Since, as illustrated in Fig. 2.11:

$$\beta = \chi - \kappa$$

the main bearing dial was driven from a differential; one side was connected to the shaft already described; while the other was coupled in the appropriate sense to a motor controlled by the gyro compass receiver. The clock still depended on own ship's speed being set manually but, subject to the accuracy and reliability of the gyro compass and the Forbes speed log, the clock maintained the range and bearings irrespective of whether own ship held a steady course, yawed, or made a small course correction or a large course change.

The introduction of a 'helm-free' Dumaresq was not the only innovation in the Mark V clock. In July 1913, Pollen and Isherwood applied for another patent which radically altered the part of the clock which generated change of bearings. This provisional patent was accompanied by a drawing illustrating the principle, if not the actual mechanical detail (Plate 29);[55] in August 1914, the Admiralty believed that this patent 'describes the mechanism of the latest type of Argo clock...already...on the open market'.[56] In the new design, one of the slipless drives was replaced by a dividing mechanism comprising a pair of linkages and a spiral cam (driven by the range clock) cut to generate a reciprocal function. The effect of the mechanism, which determined the position of the roller carriage of an Argo variable speed drive, was to displace the ball of

[55] British Patent 16,373/1913, date of application 16 July 1913, Complete Specification 16 January 1914, accepted 16 July 1914: US Patent 1,232,968 10 July 1917 (filed 11 July 1914).
[56] DNO's minute of 18 August 1914 quoted in Admiralty to C.-in-C. Home Fleets, March 1916 in 'Fire Control Apparatus: Various Patents', ADM 1/8464/181.

the drive by an amount proportional to bearing rate; thus the output shaft of the drive could be coupled directly to the bearing dials of the Dumaresq.

Why was this part of the clock changed, particularly since, at first sight, the new design seems less elegant than the old? The Dumaresq with its dials and linkages presented a not inconsiderable mechanical torque load; let this be represented by T. In both the Marks IV and V, this torque had to be generated by the static friction between the ball and disc of the variable-speed drive coupled to the Dumaresq. In the Mark V, the torque T equalled the frictional force f multiplied by the radius of the ball b:

$$T = f.b \qquad \text{or} \qquad f = \frac{T}{b}$$

Thus, f was approximately constant at all ranges, varying only if T varied with the positions of the Dumaresq elements. If the assembly force pressing together the disc and ball was set correctly so that f was less than the limit for static friction, there would be no danger of slipping, at any bearing-rate (except the very smallest - see Note 8).

In the Mark III/IV design, T was generated by the frictional force F acting at a distance r from the centre of the disc of Drive III i.e.

$$F = \frac{T}{r}$$

where r varies in proportion to the range R. If the maximum range shown by the clock is R_{max} and d is the radius of the disc:

$$r = \frac{d.R}{R_{max}}$$

F is at a maximum when R is at the minimum value which the clock can display. Thus:

$$\frac{F_{max}}{f} = \frac{b}{d} \cdot \frac{R_{max}}{R_{min}}$$

From the range scale of the Mark IV clock:

$$R_{max} = 20,000 \text{ yards and } R_{min} = 1,000 \text{ yards}$$

while measuring off the drawing of the variable-speed drive in patent 17,441/1912 gives a value for $\frac{d}{b}$ of 4.3. Thus:

$$\frac{F_{max}}{f} = 4.7$$

In the Marks III and IV, the rollers of Drives II and III were directly coupled; thus the same frictional force F had to be generated in Drive II. Hence at very low ranges, if slipping was to be avoided, Drives II and III needed four to five times the assembly force required in the Mark V. Quite apart from increasing mechanical wear, a large assembly force increased the force required to move the ball and rollers. This effect would have been particularly unfortunate in the case of Drive II; since its roller carriage was positioned directly by the Dumaresq, the increase in assembly force would have added to T, demanding a further increase. Thus, in practice, there was a limit to the permissible increase in assembly force, and slipping in the Mark IV was probably experienced at low ranges.

This limitation in the design appears to explain why the Mark V design was developed: though Isherwood may also have been concerned about the extra loads of the compass scale and the permanently-connected target course dial. However, even if the Marks III and IV suffered from some slipping, it should have occurred only at much lower ranges than would be expected in battle: and there are no indications that it was of any concern to the Royal Navy.

APPENDIX XIII

The Torbay Trials

The following notes are transcribed from *Notes, Correspondence, Etc. on the Pollen A.C System installed and tried in H.M.S. Ariadne December 1907 - January 1908*, 1908, DRAX 3/1, CC.

NOTES ON THE TORBAY TRIALS OF THE A.C. SYSTEM

The gear was not designed for any other purpose but to show that in all weathers in which guns could be kept trained, the data for the geometric range, speed, and course of a moving target could be ascertained. It was no part of the plan of the designers to consider chiefly facilities for getting the data off the chart with rapidity; it appeared that this was a matter in which only experience could indicate the best method. Consequently in considering either the time within which—after the close of the two-minutes' run—the change of range for the next three minutes was given—or its exact accuracy, regard should be had to this fact.

As it happened, in Run I., no forecast was made at all, and in Run II., owing to mis-reading of the chart, the error in the forecast was several hundreds of yards. In Run IV. the chart was mis-read by 220 yards. But in Run I. the chart agreed with the hydrographer's measurements within 31 yards—i.e., 2 per cent. of the change, Run II. within 120 yards, Run IV. within 70 yards. Runs III. and V. the forecasts were each right within 70 yards, and agreed practically with chart.

The failures to read correctly were partly due to the fact that laymen are not trained to do a piece of drill with quickness and accuracy. During the earlier runs, Mr. Isherwood and I were attempting to look after the chart, get the forecast, and give instructions for running the Service gear at the same time. When Lieut. Gipps took on the table, and the Service gear was stopped, the time taken in getting off the forecast was reduced from minutes to a few seconds. The forecasts in Runs III. and V. were actually given in less than 20 seconds after the expiration of the two minute run.

It should be remarked that in each case when a forecast was made, it was on one minute's data after the run—consequently the forecast was made for 4 minutes, not 3.

Several important improvements can obviously be made so that data shall be available as fast as they are given—it is not necessary to specify them.

A. H. POLLEN.

APPENDIX XIV

A C and Argo: Commercial Notes

1. Tactical Machines

The term 'Rate of Change machine' used for the final item in the order for the *Jupiter* gear proved conveniently ambiguous. On 18 June 1906, Pollen declared:

> I have also completed designs for an improved tactical change of range machine similar in principle, but very different in design to that already supplied to the Admiralty in fulfilment of my contract of May 1905.[1]

The key word here is 'tactical'. Pollen was describing machines which could solve the triangle of velocities and show the virtual course; however, they were not range clocks like the 'change of range machine' described in 'Fire Control and Long Range Firing'; nor, indeed, could they show or be set with 'Rate of Change' of range. Nonetheless, the Admiralty seem to have accepted this contractual sleight-of-hand, since no attempt was made to reclaim any part of the payment for the *Jupiter* gear.[2]

2. Contract Negotiations: 1906 - 1907

At the Board of Admiralty on 7 August 1906:

> Desirability of carrying out further trials [of the Pollen Aim-correcting apparatus] discussed. Controller, Director of Naval Ordnance and Director of Contracts to see Mr. Pollen and ascertain his views as to terms, on basis of 5000l. [£5,000] down to cover everything irrespective of Dockyard work &c. and to arrange as to future terms in the event of success.[3]

[1] Pollen to the Secretary of the Admiralty, 18 June 1906 in RCAI Claims Files, T.173/91 Part II. The machine was delivered on 14 May 1906: Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) pp.88-9. Sumida seems to imply that the machine was a form of clock, since 'computed ranges and bearings', corrected for ballistic factors and time-of-flight, are mentioned; however, he clearly describes the first tactical machine, called the 'crab machine', on pp.81-2.

[2] The machine supplied 'is not a machine for shooting': Pollen's counsel before the RCAI, Minutes of Proceedings, T.193/547 Part 7, p.27. The tactical machines were patented as 13,082 and 14,305 of 1906, applied for 6 and 22 June respectively.

[3] *Admiralty Board Minutes, 7 August 1906* in ADM 167/40.

This meeting took place in the Admiralty Board Room on 9 August, Jellicoe being accompanied by Harding. Pollen asked for £8,000 for the trial system, although this figure included £3,600 towards his earlier development costs.

> It was represented to him that the Admiralty ought not to be expected to make good his losses on a trial that was unsuccessful, but he replied to the effect that he was not in a position to finance the working out of the invention, and that, if the Admiralty would not do so, others were ready to undertake it. His view was that if the invention was considered by the Admiralty to be worth trying at all, its possibilities were so great that the expense of the trial ought not to stand in the way.

After some haggling, he was offered, but refused, £4,500 and it was left that he would think the matter over.

Pollen also submitted the terms under which he would be prepared, after a successful trial, to grant the Admiralty permanent and exclusive use of the invention.

> It was explained to him that a guarantee to equip 12 ships a year for 5 years...was out of the question...
> (It was roughly calculated that the <u>minimum</u> payments he asks would amount to the equivalent of £300,000 spread over 15 years....he considered that the Admiralty should pay them in consideration of his giving up all his foreign markets....)
> ...
> Mr. Pollen was told that the proposed terms, both for trial and for permanent monopoly, were out of the question.
> ....
> ...it was pointed out to Mr. Pollen that inventors usually have to perfect their inventions at their own expense....He said his terms...would have been very much higher [for] a perfected and proved system, also he was understood to say that he had had offers from a Foreign Government and from large firms to take it up.
> ....
> It was also explained to him that if the trial took place, he could not fail to acquire further knowledge of range-finding in general and of British Naval methods in particular, in addition to that which he already owes to us, and that it might be serious to us if we then decided to let him go abroad with that knowledge; we might in fact be almost obliged to accept his terms so as to keep the knowledge from others. This being so, he ought to be prepared to offer terms, both for trial and for acquisition, which the Admiralty could accept.

The last sentence suggests that the Admiralty officials were at a loss how to negotiate with Pollen: but the whole paragraph explains why the conditions for the trial insisted that Pollen was 'to attend preliminary trials to see any necessary adjustments carried out so as to ensure proper working and to demonstrate the utility of his invention...but not to be present at the final trials'.[4]

[4] 'Pollen Aim Correcting Apparatus. Notes of a meeting held at the Admiralty in the Board Room on 9th August 1906', T.173/91 Part II. *IDNS* (*op. cit.*) p.92.

On the following day, Pollen informed the Admiralty that 'The smallest sum which would enable me to carry on is £6,500'. He also requested that

> ...the agreement should include an undertaking...that, as it is not disputed that I am the sole inventor and originator of the system for obtaining the data for gunnery by the use of ranges and bearings taken simultaneously and used in conjunction with a chart gyroscopically corrected that the Admiralty will undertake not to employ any such system...except subject to agreement with me.

He also proposed a clause stating:

> The Admiralty to decide, after two months working of the instruments...whether or not they wish to acquire a monopoly of my system.[5]

The reason for this final stipulation was not given; it was probably intended to prevent any undue prevarication by the Admiralty in concluding a monopoly agreement after trials had proved successful.

The Admiralty responded on 21 August agreeing £6,500 for the development of the trial instruments. Nonetheless, at some point, Pollen was also paid an additional £802/10/- towards 'expenses which he had not anticipated' for the *Jupiter* trials, so he received more than 90% of the sum which he had first demanded. In the same letter, the Admiralty refused to entertain more than £90,000 for monopoly, although, by this time, a clock no longer figured in the negotiations; these very large sums related only to the supply of the rangefinder and plotting table.[6] Pollen replied on 24 August proposing royalties of £120,000, to be paid in three instalments, plus a fair commercial profit.[7] Then, on 27 August, Pollen wrote directly to the First Lord. He explained that he had 'come to the end of the resources that I can devote to the project' but that he was reluctant to seek further capital elsewhere because 'the admission of partners would rob me of control'. However, while expecting the Admiralty to pay for the trial instruments, he still sought a total of £255,000 over some sixteen years on the grounds that:

> ...what I have to sell is not instruments but a system, the embodiment of certain laws of gunnery which I was the first to codify....The monopoly of instruments is only incidental.

Pollen was clearly aware that his position was exceptional; 'perhaps the fact that there is no parallel to the present negotiation may explain some of the difficulties that have arisen in dealing with it'. Tweedmouth replied that 'potential values are hard things to

[5] Pollen to the Secretary of the Admiralty, 10 August 1906 in T.173/91 Part VII.

[6] Secretary of the Admiralty to Pollen, 21 August 1906 in T.173/91 Part II. *Pollen Aim Correction System. General Grounds of Admiralty Policy and Historical Record of Business Negotiations*, Admiralty, February 1913, p.7, P.1024, AL.

[7] *IDNS*, p.93.

assess...though it does seem to me that our offer was a liberal one'.[8] In his response of 7 September, Pollen complained that:

> ...the real difficulty of the position is that everybody at the Admiralty is so much overworked that no one in authority can give attention to the whole negotiation; and...every one dreads having to make out a case to the Treasury for a very unusual transaction.... I never have had...the slightest doubt...that...the business arrangements that I have proposed will be understood to be just as moderate and reasonable as the technical proposals...

On 4 September, Harding completed his 'Memorandum on the Professional and Financial Value of the A.C. System' which very probably helped to persuade Fisher that a monopoly of Pollen's gear must be obtained.[9] Thus, on 21 September, the Admiralty renewed their offer of £6,500. As Pollen had requested on 10 August:

> My Lords will agree...to decide after 2 month's working of the instruments...whether or not they wish to acquire the monopoly of your system.

If the trials were a complete success, the Admiralty would pay £100,000 for the rights to the system, including installation in 40 ships: £1,000 for each additional ship up to 80 ships: after which no further payment was to be made. In addition:

> The instruments required by the Admiralty from you to be supplied at a cost of 25% above that paid by you to the manufacturers.[10]

Yet Pollen still continued the negotiations. On 25 September, he proposed additional conditions for payment even if the trials were not successful; the Admiralty's response was that payments would then be subject to the provisions for arbitration in the contract. Then on 17 October, Pollen asked for changes in the contract terms relating to profit margins and to the conditions which defined success in the trials. These were agreed by both parties on 29 October: which enabled the Admiralty to pay Pollen the advance of £6,500 for the trial instruments on 8 November.[11]

With the immediate urgency removed, the Admiralty did not send Pollen a draft contract until 11 March 1907, but this only initiated another round of negotiations about the terms of monopoly. Points included were: when Pollen's exclusive rights to manufacture should cease (not unreasonably, the Admiralty thought this should coincide with the expiry of his patents): the Admiralty's insistence that he should maintain a permanent design staff: whether there was an obligation to pay if complete success was

[8] Jon Sumida (ed.) *The Pollen Papers* (London, 1984), Pollen to Tweedmouth, 27 August and Tweedmouth to Pollen, 3 September 1906, pp.218 and 220-1. Also in T.173/91 Part VII.
[9] *IDNS*, pp.95 and 98-9.
[10] Secretary of the Admiralty to Pollen, 21st September 1906 in T.173/91 Parts II and VII.
[11] *IDNS*, pp.115-6.

not achieved until after the first trial: and who was liable if other parties' patents were infringed by Pollen's gear. Tempers became short and Pollen at one point seems to have been accused of sharp practice. In pursuing the question of patent infringements, Pollen declared, in a letter to the Director of Contracts dated 31 July, that:

> the whole purpose and object of the Admiralty has been to take over the commercial position themselves, and to leave us in the position of an expropriated patentee.

After this, the Admiralty seems to have been reduced to (a perhaps exasperated) silence, until Pollen was sent a further draft contract on 26 November. A further round of correspondence was concluded by 23 December but the contract itself was not signed until 6 February 1908.[12] However, by that time, the *Ariadne* trials had already been held and Pollen's situation had changed entirely.

3. HARDING'S MEMORANDUM

Synthetic and Analytical Methods

In Defence of Naval Supremacy states that, in his Memorandum, Harding:

> ...rejected the separate range and bearing plots approach as "obviously unsatisfactory," choosing instead the "more correct method" of a plot of simultaneously observed ranges and bearings from which the target's course and speed could be measured.....[13]

It is true that, almost twenty years later in his testimony to the RCAI, Harding claimed that dual-rate plotting was considered as an alternative to course plotting but, under cross-examination, he admitted that, in his Memorandum: 'The double rate is not represented at all'.[14] This is born out by the document itself, which states:.

> THERE are two principal methods of determining the rate of change.
> (a) THE SYNTHETIC METHOD
> BY dividing the difference between successive readings at definite periods of time by a convenient multiple of the time taken, or by [noting] the time taken to alter a definite amount.
> This method is obviously unsatisfactory.
> ....
>
> (b) THE ANALYTICAL METHOD
> Determining the value of the separate elements which produce the rate of change viz. the speeds and courses of the opposing ships and their bearings to one another....

[12] *IDNS*, pp.116-9.
[13] *IDNS*, p.96: see also p.91.
[14] T.173/547 Part 14, pp.9, 11-2 and 34.

He also noted that 'the speed and course of the enemy are merely estimated': and that both methods were part of the 'present system' which 'gives results which though they are not good are not very bad'.[15]

Plotting by the Coastal Artillery

Pollen was later accused by Dreyer of making a rechauffé (warming up) of the Watkin system used in British coastal defences and tried unsuccessfully in *Arethusa*.[16]

> The idea of maintaining the range by plotting ranges and bearings of enemy and drawing a meaning line through them was first used by Colonel Watkins [*sic*] of the R.A. and is the system which the R.A. have used in the Watkins [*sic*] position finders for 25 years.[17]

In 1909, Pollen himself claimed that he had never heard of the Watkin 'inventions...until 1906....and could not now give an intelligent account of his system'[18] yet the depression rangefinders used in one version of the Watkin system[19] are mentioned in the Memorandum sent by Lawrence to Selborne in May, 1904.[20]

As a member of the Royal Marine Artillery, Harding was well acquainted with the Watkin gear.[21] He would have recognised that the originality in Pollen's proposals lay not in course plotting *per se*, but in his conviction that this type of plot could be made from a ship at sea.

4. BACON AND MECHANISED GUNNERY

Bacon responded to Pollen's letter of 27 February 1908 (which the inventor printed for circulation in the Admiralty) in the following terms:

> The flexibility of the powers of a man either cerebral or mechanical has to be balanced against the rapidity of operation of a machine. The liability to error of both from different causes is a variation of the problem and the available spare men must be balanced against the available spare machines. It is as I have previously pointed out the knowledge of the adaptability of men & matter at sea which draws the only distinctive line between sea & land experience.[22]

[15] Harding, 'Memorandum upon the Professional and Financial Value of the A.C. System' with Harding to Jellicoe, 4 September 1906 in T.173/91 Part VII.
[16] Frederic Dreyer, 'Summary' n.d. but after 1923 and probably 1925, p.15 in DRYR 2/1, CC.
[17] Dreyer to Hughes-Onslow, 19 October 1908 in T.173/91 Part VII.
[18] *PP*, 'Notes, Etc. on the Ariadne Trials', April 1909, p.214-5.
[19] Anita McConnell, *Instrument Makers to the World. A History of Cooke, Troughton & Simms* (York, 1992) p.65.
[20] 'Memorandum' with Lawrence to Selborne, both 9 May 1904 in 'The Pollen Rangefinder' in ADM 1/7733. See also *PP*, 'Memorandum on a Proposed System for finding Ranges at Sea...', July 1904, p.16.
[21] Harding before RCAI, T.173/547 Part 14, p.7.
[22] *IDNS*, p.133.

While there can be no doubt that Bacon was sceptical of the value of complex mechanisms which could get out of order, he was also willing to introduce new instruments when their value and reliability were proven, as is shown be the innovations made while he was DNO (see Chapter 3). Thus his opposition to all fire control instruments was not as absolute as suggested by Sumida.

'The Quest for Reach' proposes that:

> Bacon...was opposed in principle to the mechanization of fire control on the grounds that it was inherently unreliable....
> Bacon's distrust of fire control instruments and faith in spotting probably owed something to his experience as captain of the *Dreadnought*. During gunnery experiments in this ship in early 1907, Bacon had found the new model Barr and Stroud 9-foot-base rangefinder to be unsatisfactory, and that because of good loading drill...four-gun salvoes could be fired at 15-second intervals, which was triple the speed of earlier battleships. In theory, such rapid fire greatly increased the value of spotting when the range was changing because the shift in the relative positions of the target and firing ship between salvos was reduced by a third.[23]

Firstly, Bacon's criticism of the rangefinders was only that they required target ' "finders" of much greater aperture'. Secondly, as mentioned in Chapter 3, the loading interval (36 seconds for A turret and 29 seconds for the remainder) was no guide to the actual, much slower, firing rate.[24] And, thirdly, these conclusions seem to suppose that *Dreadnought* would have fired and spotted without the aid of her Vickers clocks to keep the change of range between salvoes.

Similary *In Defence of Naval Supremacy* states:

> Bacon's opposition to mechanized methods of gunnery included mechanized gunlaying as well as sight-setting. The Petravic system of automatically discharging guns at a predetermined point during a ship's roll with the aid of gyroscopes was tried in September 1908 but rejected as "being not suitable for adoption under sea going conditions," a decision that appears to have been prompted by the same distrust of gyroscopes that had operated in the case of the *Ariadne* trials. The Naval Ordnance Department even declined to support the work of Percy Scott...[25]

In fact, such distrust was amply justified by the Petravic trials, during which the gyro was deranged by the shocks of firing and by changes in course and speed.[26] Further, as the present author has tried to show elsewhere, at most Bacon did not support further development of the early elevation-only form of director, and was himself responsible for

[23] Jon Sumida, 'The Quest for Reach' in Lt. Col. S D Chiabotti (ed.) *Tooling for War: Military Transformation in the Industrial Age* (Chicago, 1996) p.64.
[24] Captain R H Bacon, *Report on Experimental Cruise*, 16 March 1907, pp.28, 84-5 and 96-8, ADM 116/1059.
[25] *IDNS*, p.153.
[26] 'Trial and Report on Obry (Petravic) Gunfiring Apparatus' in ADM 1/8011.

placing the order with Vickers which produced the first practicable Director, as fitted in the battleship *Neptune* in December 1910.[27]

5. CONTRACT NEGOTIATIONS, 1909 - 1910

On 21 June 1909, the Admiralty invited Argo to tender for a production order of at least 30 rangefinder mountings.[28] On 23 June, Pollen responded with a price of £1,915 (with indicators), though he also proposed a royalty of £250 per ship per annum.[29] After being ordered ashore from *Natal* prior to gunnery exercises, Pollen met with Bacon on 13 November. At the end of the month, the outgoing DNO advised his successor, Captain Moore:

> The really useful portion of Mr. Pollen's apparatus appears to be the gyroscopically controlled range-finder....but there is no reason why he should be paid any large royalties on the instrument....If Mr. Pollen can be put on the same basis as all other Admiralty contractors a difficulty which has existed for the last two years would be successfully removed.[30]

However, at a meeting on 10 December with the ADNO (Captain Craig), the plotter was still being discussed.

> It was explained to Mr. Pollen that the only portion of his apparatus at all likely to be adopted at present were:-
> (a) ...rangefinder mounting [with] indicators
> (b) Automatic Plotting Table.
> ....
> It was suggested that he should state what terms he would accept on the following basis:

Orders	)	...75 sets of (a)	)	to be guaranteed by the Admiralty
	)		)	within 5 years (no definite
for	)	...50 sets of (b)	)	minimum within any one year).

Pollen then indicated that he would be prepared to accept a fixed royalty of £1,000 on each mounting or table. He also proposed that:

> ...if the Admiralty saw its way to paying £20,000 in advance, it would enable Mr. Pollen to obtain a Controlling interest in the firm of Cooke & Son of York, where the apparatus could...be manufactured under Mr. Pollen's direct control.[31]

[27] John Brooks, 'Percy Scott and the Director' in David McLean and Antony Preston (eds.) *Warship 1996* (London, 1996) pp.168-9.
[28] *IDNS*, pp.164-5. Secretary of the Admiralty to Argo, 21 April 1909 in T. 173/91 Part VII. There are no indications that the observer's correcting mechanisms were ever completed.
[29] *IDNS*, p.165. *Record of Business* (1913) (*op. cit.*) p.10.
[30] *Paper prepared by the Director of Naval Ordnance for the information of his Successor*, 24 November 1909, p.4, AL.
[31] 'Pollen Aim Correction System. Notes of what took place at the Conference...on...10th December 1909' in T.173/91 Part VII. In 1908, the Linotype company had ceased manufacture in Britain: McConnell, *Instrument Makers to the World* (*op. cit.*) pp.74.

Once in office, Moore followed Bacon's advice, further negotiations focusing solely on the mounting, with transmitters and range and bearing indicators, and on a single inclusive price for each set. On 22 January 1910, Pollen quoted a price of £1,750 each for 75 sets supplied over five years with monopoly, while offering a 15% reduction on non-monopoly terms.[32] However, during the December meeting, he had revealed that the Linotype Company had quoted only £275 for the manufacture of each mounting with transmitters: although he had also proposed that a cost to him of £380 should be assumed to allow 'a margin for alterations and improvements...and also a proportion of the cost of Tools, on which about £1,000 has been spent'. He also stated that the Argo Company cost about £5,000 to £6,000 a year to run.[33] Thus his own figures pointed to a profit of at least 124%, which probably explains why, by the beginning of March, he was writing of a 'fraudulent contractor theory' apparently held by some in the Admiralty. In January, the Admiralty had warned Pollen that no decision could be expected before the start of the next financial year[34] but their first counter-offer, of 11 April, was for only 15 sets at £1,000 each, without secrecy. Since Argo would now be able to seek customers abroad, they were told that:

> It is not desired at present to fix any term of supply beyond the first 15, but it is considered that there should be substantial reduction in price if any further sets are later on ordered from your company.[35]

Pollen replied temperately, but he insisted, contrary to the earlier indications of manufacturing cost, that:

> ...the bare cost of the instruments...would exceed the amount offered....it is a commercial and industrial impossibility for us to accept.[36]

In a private letter to the First Lord, McKenna, also dated 13 April, Pollen expressed his 'profound regret that the Board do not consider monopoly worth preserving' and implied that he might be compelled to sell to 'foreign - and perhaps hostile - governments'. He also argued that the expected savings to the Admiralty were largely illusory, since his success abroad would oblige the Royal Navy to purchase more installations and, by promoting more rapid development, would make it impossible to keep a standard pattern for long. And, in any case, foreign navies would wish to manufacture the gear in their own

[32] *IDNS*, pp.197-8. Minute by Director of Navy Contracts to Controller, 18 April 1910, f.1 in MCKN 3/15.
[33] 'Conference 10 December 1909' (*op. cit.*).
[34] *IDNS*, pp.197-8.
[35] Secretary of the Admiralty to Argo Co. 11 April 1910 in T.173/91 Part VII.
[36] *IDNS*, p198. Pollen to the Secretary of the Admiralty, 13 April 1910 in T.173/91 Part VII.

countries. He then proposed that secrecy should be maintained and an order placed for 45 sets, still at £1,750 each, which, he declared, 'would leave no divisible profit at all'. He also asked for an advance of £25,000 since:

> ...owing to my having understood before Xmas, that an order for 75 units was virtually decided, I entered...into an obligation to acquire a share in an important factory...and have consequently to find £15,000 before June 15th.[37]

The request for prices at the meeting of 10 December hardly justified such an optimistic interpretation.

On 19th, Pollen met with McKenna and Admiralty officials to discuss costs but not, as he had hoped, the question of monopoly; afterwards, Pollen wrote to McKenna with a clearly implied threat to make public the abandonment of secrecy: but he also offered some reduction on price, proposing £1,600 each for the 45 sets.[38] This concession was probably welcome to the Controller, Jellicoe, who appears to have become doubtful about the initial offer to Pollen. On 18 April, as directed by Jellicoe, the Director of Navy Contracts, F W Black, submitted his 'personal opinion as to a fair manufacturing price for the...Apparatus for which the Admiralty have offered Mr. Pollen £1000 per set for 15 sets'. Using the figures given by Pollen in December, including the contingencies, Black calculated that the cost to Argo of a mounting with a pair of indicator was £500; he also added £100 per set for additional tooling. However, after making allowances for a proportion of the costs of running Argo and for interest charges, Black concluded that, without secrecy, a price of £1,200 would be necessary to yield a 'substantial and liberal' profit.[39] These figures must have influenced the subsequent negotiations. By 27 April, the parties were close enough for the Admiralty Board to give its general approval:

> Details to be arranged by the Controller.[40]

On the 29th, Argo was sent the Admiralty's offer to purchase 45 sets over the next three years at £1,350 each, while secrecy was to be maintained until the end of 1912; the first

[37] Pollen to McKenna, 13 April 1910 in T.173/91 Part VII.
[38] Pollen to Spender, 12 April 1910: Pollen to McKenna, 19 April 1910 with Enclosure, 20 April 1910: in MCKN 3/15. As an alternative, Pollen also proposed a price of £1,100 with secrecy payments of £540 per month for three years.
[39] DofC, 18 April 1910 (*op. cit.*) p.6. On the same day, Moore, the DNO, provided his own similar estimates (also in MCKN 3/15) in which the corresponding figures were £470 and £85; however, he used Pollen's estimate without contingencies but assumed, wrongly, that it did not include a manufacturer's profit of 25%.
[40] *Board Minutes, 27 April 1910*, ADM 167/44.

£15,000 of the value of the contract was to be paid in advance. The price covered payment by the Admiralty of all the Argo Company's charges of £6,000 per annum for the three years. In consequence, any other parts of the A C system would be supplied at the cost to Argo plus 'a fair commercial rate of profit only'. Argo were also required to acknowledge that the agreement of 18 February 1908 was 'a dead letter' and that the Admiralty manual plotting table did not infringe their patents.[41]

Although the 'Argo Company accepted the conditions "without qualification" on the day they were offered', Sumida proposes that:

> ...Pollen's acceptance of the Admiralty's unfavorable terms of purchase for only a portion of his fire control system...provided a margin of profit that was too small to enable the Argo Company to carry on experimental work on the remaining instruments...[42]

Yet, when the Contracts Branch reviewed the history of Argo's business with the Admiralty in 1913, they noted that:

> In May 1912, the Argo Company reported that the actual manufacturing cost of the 45 sets of range-finder mountings (including 30 per cent. profit to the manufacturers) had worked out at just about 29,000l. ...[43]

i.e. £645 per set, not much more than Black's estimate of £500 plus £100 for tooling. The value of the contract was £60,750. In 1910, the Admiralty's estimate of the manufacturing costs was £27,000, while Pollen's figure for the cost of running Argo for three years was £18,000; this left a profit of £15,750 i.e. 35%. Black allowed that

> ...33 per cent. [as] an ordinary trading profit...would be a good percentage, but it may be regarded as small having regard to pioneer work &c.[44]

However, in this case, the Admiralty was also financing all Argo's running costs, including experiment work, at the present rate of expenditure, while the firm developed the rest of the A C system. If Pollen's own lower estimate for manufacturing costs - £380 including a contingency for tooling - is used, the profit would have been 73%. Thus, in 1910, the terms of the contract cannot have appeared unfavourable to either party.

[41] Secretary of the Admiralty to Argo Co. with enclosures, 29 April 1910 in T.173/91 Part VII.
[42] *IDNS*, p.201.
[43] *Record of Business Negotiations*, p.17.
[44] DofC, 18 April 1910, p.6.

6. ADMIRALTY SALARIES.

The following salaries are taken from *Whittaker's Almanack, 1914*, p. 245.[45]

Director of Naval Construction, E. H. Tennyson-d'Eyncourt	£2,000
....	
Engineer-in-Chief of the Fleet, Eng.-Vice-Adm. Sir H. J. Oram...	£1,500
....	
Director of Naval Ordnance and Torpedoes, Rear-Adm. F. C. T. Tudor...	£1,500
....	
Assistant Director of Naval Ordnance, Capt. J. D. Dick...	£ 800

7. POLLEN'S SALARY

The Argo Profit and Loss Account (Appendix XV) shows a £1,000 increase in directors' salary for 1909, yet the Notes of the Admiralty meeting on 10 December 1909 state that Pollen's salary was £1,500. Before the RCAI in 1925, Pollen said that the increase to £2,500 was in 1911 and that payments continues until 'six years ago'.[46]

[45] Reference courtesy of Mr John Covington.
[46] T.173/547 Part 15, p.62.

APPENDIX XV

ARGO COMPANY ACCOUNTS

THE 1923 ACCOUNTS

In preparing their submission to the RCAI in 1923, the Argo Company submitted their audited accounts to Mr Alan Rae Smith of Deloitte, Plender, Griffiths & Co. From these, he prepared amended Balance Sheets and Profit and Loss Accounts for the six years ended 31 December 1913. These accounts were preceded by a report by Rae Smith; the more important paragraphs are quoted below.[1]

REPORT

....	....
Formation of the Company	2. The Company was registered on 31st December 1907 with a Capital of £1,000 divided into 20,000 shares of 1/- each. On the 9th March 1908 the Company entered into an agreement with Mr. A. H. Pollen, under which the latter assigned to the Company his interests and obligations under a contract between himself and the Admiralty, dated 18th February 1908, with the exception of the sum of £6,500...already paid by the Admiralty to Mr. Pollen.
Initial Issue of Share and Debenture Capital.	3. In consideration of the assignment of the above-mentioned agreement, the Company issued 17,992 shares of 1/- each (credited as fully paid) £899. 12. 0...and £3,500 5% First Mortgage Debentures fully paid (part of a total Authorised of £10,000)... The foregoing consideration of £4,399. 12. 0 appears under the heading of Goodwill in the Balance Sheets... The remaining 2,008 Shares of the total Authorised Issue were issued and paid for in Cash (£100. 8. 0).
Further Issue of Share Capital	4. In 1911 the Authorised Capital was increased to £3,600 by the creation of 250 6% Cumulative Preference Shares of £100 each, of

[1] Report and Accounts in RCAI Claims Files for Argo Company and A H Pollen, T.173/91 Part I, PRO.

	which 234 were issued for Cash. £50 was called up on each share, making £11,700.
Further Issue of Debentures	5. The £3,500 Debentures which were issued in 1908 were redeemed in 1909. In 1913 a further issue of £10,650 Debentures was made for cash at par.
Receipts from sources other than the Admiralty	6. ...it would appear that from the inception of the Company up to the end of 1913 the Company transacted business practically solely with the British Admiralty....the total...from sources other than the Admiralty amounted in the six years...to...£154....
....	....
Period prior to incorporation of the Company	8. ....Previous to the Company becoming interested in the matter Mr. Pollen had been personally concerned, in a private capacity, with the inventions and the development thereof, and no separate records or accounts were kept by him in relation thereto. Mr. Pollen has furnished me with a list of the payments made by him between 1905 and the incorporation of the Company, and representing the expenditure incurred by him....These payments... total £6,870. 2. 2.... During the same period...Mr. Pollen informs me that he received from the Admiralty sums totalling £11,800, of which £2,000 was to cover expenditure which he had incurred prior to 1905....giving a surplus of receipts over expenditure of...£2,930.
....	....

9th October 1923 [signed] A Rae Smith

Profit and Loss Accounts

The 'Amended Trading and Profit and Loss Accounts for the Six Years ended 31st December 1913' were appended to the report as Statement B.

Without changing any of the figures, the original tabulation has been rearranged on the next page into a summary table showing gross profit and net profit or loss: together with a detailed table showing expenses, salaries, etc.

Balance Sheets

The 'Amended Balance Sheets for the Six Years ended 31st December 1913' were appended to the report as Statement A.

The original 'side-by-side' layout has been rearranged with Creditors above Debtors. The method of incorporating the profits and losses has been slightly simplified, but the allocations to one 'side' or the other remain unchanged.

ARGO PROFIT AND LOSS ACCOUNTS

	1908	1909	1910	1911	1912	1913	Total 1908-1913
Profit and Loss							
Receipts from Admiralty	11,500	6,107	3,719	8,180	60,711	13,254	103,471
Other sales	24	75	9	14	32		154
less Purchases, balance of stock, etc. (see Note)	-2,179	-2,657	-2,682	-5,566	-34,174	7,165	-54,423
Gross profit	9,345	3,525	1,046	2,628	26,569	6,089	49,202
Dividends			49	900	949	949	2,847
less Expenses, salaries, etc. (as detailed below)	-4,919	-5,963	-8,651	-11,050	-12,437	-12,807	-55,827
Net profit or loss	4,426	-2,438	-7,556	-7,522	15,081	-5,769	-3,778
Details of Expenses							
Travelling and directors' expenses	972	583	257	480	780	638	3,710
Staff salaries	1,081	581	2,306	4,092	4,545	2,742	15,347
Directors' salaries	2,373	3,575	3,625	3,658	3,700	3,600	20,531
Patent fees	229	52	136	343	608	2,590	3,958
Experimental work			69	763	708	1,075	2,615
Motor car upkeep and depreciation		663					
Expenses of rangefinder trials in U.S.A.						99	99
Debenture interest	141	30				282	453
Bank charges and interest			300	454	648	537	1,939
Life insurance (on Pollen)				153	175	245	573
General and other expenses	123	479	1,958	1,107	1,273	999	5,939
Total	4,919	5,963	8,651	11,050	12,437	12,807	55,827

Note: These items cover:

purchases

balance between stock at the end and commencement of the year

erection expenses

carriage

wages (maximum of £516 in 1911).

ARGO BALANCE SHEETS

	1908	1909	1910	1911	1912	1913
Creditors						
Issued Capital	1,000	1,000	1,000	12,700	12,700	12,700
First Mortgage Debentures	3,500					10,650
Receipts on account of Goods not delivered			15,000	11,278		
Loans from Bankers			7,500	13,730	13,730	6,730
Sundry Creditors	1,804	5,431	699	3,179	8,537	5,548
Credit balance		4,426			-13,590	
Profit for year	4,426				15,081	
less Loss for year		-2,438				
less Dividend paid		-500				
	10,730	7,919	24,199	40,887	36,458	35,628
Debtors						
Goodwill	4,399	4,399	4,399	4,399	4,399	4,399
Plant, furniture, fittings, etc.			383	1,753	1,233	1,222
Stock on hand	200	1,978	303	3,682	1,069	4,554
Motor car		893				
Investments (at cost)			12,650	15,650	16,650	16,650
Cash at Bankers and in Hand	124	131	388	530	5,415	1,020
Sundry Debtors	6,007	518	8	1,283	7,692	3,505
Debit balance			-1,488	6,068		-1,491
Loss for year			7,556	7,522		5,769
	10,730	7,919	24,199	40,887	36,458	35,628

Inspection of Argo's Books: 1912

In May 1912, Argo requested a payment of an additional £26,000 on the contract for the supply of rangefinder mountings. This led to an inspection of their books. After the abandonment of secrecy, in February 1913 the Contracts Branch produced a record of the business relationship between the Admiralty and Pollen and the Argo Company entitled *Pollen Aim Correction System. General Grounds of Admiralty Policy and Historical Record of Business Negociations.* Amongst much else, this records the information supplied in 1912. The following table compares the impressions created then with what can be deduced from the company accounts as summarised (at Argo's request) by Alan Rae Smith in 1923.

	Record of Business (1913)	1923 Accounts
p.14	133. The first inspection of the books revealed...that...Argo...had expended much more than the 6000l. [as anticipated in 1910] on their staff... The bulk...went on high salaries e.g. to Mr. Pollen 2500l. per year, and to...Mr. Isherwood 1000l. a year, and to ex-Naval Officers who had joined the firm Lieut. Gipps, 1000l. a year, Lieut. Riley 792l. a year; Draughtsmen, 2700l. per year.	The accounts show the annual figure for staff salaries peaking at £4,545 in 1912. This is less than the total for salaries, Pollen's excluded, of £5,492 given in the *Record of Business*. Either the salaries for draughtsmen had been exaggerated: or Isherwood was paid as a director (though, in Pollen's and Isherwood's many joint patent applications, only Pollen is named as a Director).
p.14	134. These gentlemen had been employed partly in perfecting the 45 sets, but also largely in designing and experimenting with other Argo A.C. apparatus e.g. range clocks to which invention alone the Compay attributed an expenditure on design and development of 13700l.	The manufacturing cost of the 6 Argo clocks supplied to the Admiralty was £971 each (*Record of Business* p.16). The maximum annual expenditure on experimental work was £763 (1911) and on salaries £8,245 (1912). Development work on the clock began in early 1911 but detailed design around mid-1911. It is difficult to understand how £13,700 could have been spent by May, 1912.
p.17	In May 1912 the Argo Company reported that the actual manufacturing cost of the 45 sets of range-finder mountings (including 30 per cent profit to the manufacturers) had worked out just about 29000l. but that instead of spending only the expected 21000l. on salaries and expenses...during the contract period they were actually spending about 29000l....and 9000l. for experimental work and increases to staff to overtake time lost by their originally designing alterations for the Natal gear which the Admiralty afterwards refused to accept.	In 1910, Pollen had estimated that the cost of running Argo (which presumably included salaries and expenses) was about £6,000 p.a., a figure which is consistent with the 1909 accounts. In that case, the £21,000 expected by the Contracts Branch represented running costs for 3½ years. However, the contract agreed in April 1910 was for 3 years; since secrecy expired in December 1912, it appears probable that the rest of the contract conditions applied to the same three calendar years 1910-1912 inclusive. The total expenses for these three years in the accounts was £32,138, which is not very different from the estimate of £29,000: but it should have been compared with £18,000 rather than £21,000. The total for 'Experimental work' in the accounts for the three years is only £1,540. However, an unknown proportion of 'Purchases' probably included experimental instruments.
p.17	167. They further stated that the Company was about 8000l. to the bad at the time when the order for the 45 sets was given. .... 171. ....on Mr. Pollen's own admission the 11500l. paid to him in May 1908 left him 5700l. to the good after paying all expenses incurred on the system up to that date.	The report on the accounts states that Pollen was £,2,930 in surplus at the time that Argo was incorporated. The Company then made a profit of £4,426 in 1908. If expenses were uniform throughout the year, at least £2,500 was incurred from June to December 1908. Thus, after the payment of £11,500 in May, Argo and Pollen (the major shareholder) were between them about £9,800 to the good.

		The Company made losses in 1909 and 1910 of £2,438 and £7,556. In 1910, there was a large increase in staff salaries to £2,306 for the year; it may be assumed that most of this was incurred after the contract was placed and additional draughtsmen were engaged. Assume that salaries and general expenses from January to April 1910 did not exceed the bill for the whole of 1909 i.e. £1,060; also that only £1,208 of the directors' salaries had been paid by the end of April. Thus, when the contract was placed, the loss for the year to date would not have exceeded £1,935. On this basis, the Company alone was still just in profit, to the amount of £53. In any case, the 1910 accounts gave a very pessimistic view of profitability, since none of the £15,000 advance payment was included in that year's receipts. As for Pollen himself, the redemption of the debentures in 1909 had added £3,500 to his earlier surplus of £2,930. Thus, in 1912, Pollen understated his profit for 1908 and greatly exaggerated the company's accumulated loss by April 1910.

ADMIRALTY PAYMENTS TO ARGO

The *Record of Business* included as Schedule A 'Approximate details of payments made by Admiralty to Mr. Pollen and Argo Company in connection with Pollen A.C. System (including sums remaining to be paid on orders not yet complete)'.

The table below compares this schedule with the 1923 accounts. Although the totals from year to year do not always tally and neither set of figure shows explicitly the £15,000 paid in advance on the order for 45 rangefinder mountings, the overall totals from the two sources agree closely.

The schedule from the *Record of Business* appears to have been used as the basis for Table 23 in *In Defence of Naval Supremacy*. The only difference is that Sumida assumed that Argo were paid to install all six Argo clocks. With the rapid deterioration of relationships between Argo and the Admiralty from the beginning of 1913, it is most unlikely that any representatives of the firm would have been allowed on board any Royal Navy ship by the time the clocks were ready for delivery.[2]

Schedule A, *Record of Business*, 1913			1923 Accounts
1905	Two observer set obtained for trials in "Jupiter".	4,500	
	Extras	800	
1906	Set purchased for trial in "Ariadne".	6,500	11,800
1908	In return for his services, and to secure secrecy up to November 1909 Mr. Pollen was paid	11,500	11,500
1909	Set purchased for trial in "Natal" (including accessories and cost of installation, etc.)	7,660	6,107
1910	Trials having extended over the date fixed for secrecy (November 1909) further payments for temporary secrecy were made, totalling about	2,160	
	45 sets of gear for gyro control of range-finders purchased at 1350l. per set (approximate payment, including tools and accessories afterwards ordered to be supplied with each set and excluding cost of gyroscopes afterwards cancelled as regards certain of the 45 sets)	60,750	3,719
	Subsequent purchases:-		
1911	Additional gear for Natal's set	210	8,180
1912	Spare parts &c. for 45 sets	6,975	
	Rate plotter for "Orion" including cost of fitting	580	
	Drawings, &c	200	60,711
	Argo improved clock, six in number for trial, at 2133l. each	12,798	
	Cost of installing one of above	150	
1913			13,254
	Total	114,783	115,271

[2] G B Cobb, Assistant Director of Contracts, 'Royal Commission on Awards to Inventors. Answer by Department to Claim 1451 of the Argo Company and Arthur Hungerford Pollen...', 19 December 1922 (in T.173/91 Part I) repeats the 1913 schedule and includes the cost of installing only one clock.

APPENDIX XVI

Moore's Recommendations, 1912

Extract from Third Sea Lord's Minute, 13 August 1912[1]

In any case, the Argo Company possesses no knowledge that the Service is lacking, indeed the whole of the knowledge it has of the Fire Control necessities has been derived from the exceptionally privileged position in which Mr. Pollen has been placed by the Admiralty; everything that the Argo Company professes to achieve, can be equally well performed with the Dreyer instruments: except that the Argo Company still advocates "True Course and Speed plotting" as an essential, whereas the Service and Dreyer prefer the "Time and Range" and "Time and Bearing" curve system. (The True Course and Speed system has been tried over and over again and always fails). His [Pollen's] clock may or may not prove better than Dreyer's, under monopoly terms it will certainly be more expensive. I do not see any reason for continuing the privileged position of this inventor, he has been handsomely and generously paid for his work in the past, and in my opinion it is full time that he was placed in the same position as all other inventors. Apart from the financial disadvantages of Monoply [sic] terms, it restricts our area of research...and it conveys a false impression in the Service of his position, enabling him to acquire most confidential information immediately we make any advance, and such information naturally leaks farther afield. I believe Messrs Barr and Stroud have a very fair knowledge of our system, and indeed are working very near it in the matter of instruments. I would again urge the desirability of ending this unsatisfactory condition of affairs, by releasing Argo Company from its present Secrecy

[1] A G H W Moore, Extract from 3rd Sea Lord's Minute, 13 August 1912 in MB1/T22/174, Papers of Prince Louis of Battenberg in Mountbatten Papers, University of Southampton Library.

clause, warning Mr. Pollen against divulging any Naval Secrets in his dealing with other Markets, but I have a strong suspicion that his chief marketable ware is his knowledge thus confidentially acquired.

(Intd.) A.G.H.W.M.
13.8.12.

MOORE TO BATTENBERG, 19 SEPTEMBER 1912[2]

Personal

Greenwood
Fareham
19. 9. 12

Dear Prince Louis

I have read the letters you gave me & return them herewith. Mr. Pollen's being a "personal" letter to Peirse I do not comment on it, although it contains a strong attack upon me. The general subject matter of his letter has been dealt with over & over again on the official papers.

But as regards Peirse's letter & Memorandum - It is perfectly true that by placing Mr. Pollen in the position of a favoured inventor, we have put him in possession of the most confidential items of our Fire Control System, and we are constantly being pressed by Mr. Pollen to pay him large sums of money to keep that information for our exclusive use (His way of putting it is in the form of saying we pay him consideration for the restriction of his profits by limiting his market). Each time we pay him thus (monopoly rights) he gains more Confidential knowledge, and [thus] his most valuable marketable article rises in proportion, so that Monopoly prices rise, it is a chain round our necks being forged more and more relentlessly. If there was no other system achieving equal results with Pollens then there would be no choice (or very little) for us; but there is another system; it is almost identical, it is Dreyers; the mechanical details are different but with one exception the principles are the same -

(a) Both depend upon a Range finder which automatically transmits range and gyro corrected bearings.

[2] Moore to Battenberg, hand-written letter of 19 September 1912, Moutbatten Papers, MB1/T20/147.

(b) Both place data thus obtained upon a clock which, set going, transmits the corrected range by steps to the gun sights (or a follow the pointer transmitter) & both clocks keep the rate of clock adjusted as the bearing of enemy alters.

(c) The difference lies in the data obtained by (a).

Dreyer gets Rate of Change of range
& " " " " bearing
Pollen gets Speed & Course of Enemy

from which rates are automatically put on the Clock, but he can set his clock equally well with the data that Dreyer gets.

I agree with a great deal Peirse has written in his Memorandum but...so far Dreyers system has given the most reliable results....

...after the Natal trials all that was successful of the Pollen gear was accepted i.e. The gyro controlled Range Finder, & a very handsome Monopoly price paid for 45 sets. The Clock was not then completed. The plotting table aiming at finding "True Course & Speed of Enemy" failed, & until recently Mr. Pollen has not produced a better table. If he can produce one there would be no objection to trying it in conjunction with the Clock & Rangefinder, and Mr. Pollen is quite mistaken in thinking I oppose this. He knows I do not think he has yet, or is ever likely to produce equal results with True Course & Speed plotting to those obtained by Rate plotting under Seagoing fleet conditions. What I am opposed to is paying him Monopoly prices when we have practically the same principles at work in Dreyers system - I am so far from being opposed to Pollens Clock that I have begged him for his own sake to push on with it & perfect it, as I knew Dreyer was going ahead, & I believed Argo Company's work would be more accurately carried out. I have been for nearly a year trying to get contracts placed for 5 Argo Clocks to compete with Dreyers 5 going to King George V class - but Pollen has held out always on a prohibitive price based on Monopoly terms. Mr. Pollen has always made a great parade of his patriotic feelings preventing him from seeking other markets, but if we propose to accept that kind offer of patriotism without paying him for it, he threatens to go abroad and <u>trade upon the Confidential Knowledge he has acquired by reason of his specially favoured treatment -</u>

I believe that both Dreyer's & Pollens' systems will produce about equal results. Dreyer's is the more developed at present, but Pollen's workmanship is probably better & less liable to get out of order. If Pollen's table proves better than rate plotting, then it is a question of how much better compared to price, but meanwhile everything with

Pollen hangs up, because of the demand for Monopoly money (it might be called Hush money).

I don't think Peirse is conversant with the latest details of Dreyers gear, although as he is an advocate of "True Course & Speed plotting" such knowledge would not altogether change his opinion.

....

I agree that it is unfortunate Mr. Pollen should have acquired so much Confidential information, but I think the time has long since arrived when we should shake ourselves free, and let Mr. Pollen prove the truth of his contention that he has a waiting market elsewhere.

On this point I cannot find any argument for altering my opinion, but I should be the first to welcome any improvement in plotting that would give us a correct forecasted rate. Pollen has never done so yet or got within measurable distance of it.

Yrs. sincerely,

G. W. Moore

Appendices to Chapter 5

APPENDIX XVII

DREYER'S EARLY CAREER

Frederic Charles Dreyer was born on 8 January 1878 at Parsonstown, King's County, Ireland, the second son of the Danish-born astronomer John Louis Emil Dreyer (1852-1926).[1] From the Royal School, Armagh, Dreyer entered *Britannia* in 1891 and, in his final examinations, was placed fifth in his term. He continued to obtain Class I certificates in nearly all his courses for sub-lieutenant and lieutenant (promoted July 1898) and for gunnery lieutenant; in 1900, he was the author of *How to get a First Class in Seamanship.* In 1901, on the demanding Advanced Course for gunnery and torpedo lieutenants at Greenwich, he came first, with honours, in his class of three.[2] In January 1902, he became an instructor at the Naval Gunnery School, Sheerness, where senior staff officers included Lieutenant Fawcet Wray, the inventor of the first range clock, and Lieutenant J D Edwards who introduced the Royal Artillery's bracket system into the Navy.[3]

From the start, Dreyer showed an enthusiasm for invention, beginning in 1895 when he conceived 'a range-keeper with object glass of varying focal length [although this was] not sent in as optical difficulties were too great'. By July 1898, he was the lieutenant in charge of the rear barbette of the *Repulse* with its pair of 13.5 inch guns and, in the following August, he did send in a proposal (though it was not taken up) for a 'mechanism for connecting a medium calibre gun [a 12-pr] to a heavy gun so that the former's projectiles could be used as a Hitting Gun Range finder for the heavy gun ("Pilot Gun")'.[4]

In June 1903, Dreyer joined the new battleship HMS *Exmouth* as Gunnery Lieutenant. This gave him the opportunity to employ his pilot gun method, now using

[1] *DNB, 1922-1930.*
[2] Examination certificates in DRYR 1/2, CC.
[3] Admiral Sir Frederic Dreyer, *The Sea Heritage* (London, 1955) pp. 32 and 45.
[4] 'Rear Admiral Dreyer's Inventions' in DRYR 2/1. *Sea Heritage* (*op. cit.*) pp.29-30.

the ship's secondary 6-inch guns; Dreyer 'ranged on the target with the 6" guns and when these were hitting, he applied a correction... to allow for the difference in the external ballistic characteristics for the 6" and 12" guns... and in each year's Battle Practice scored a hit with the first 12" shot fired'.[5] In May 1904, his ship recommissioned as the flagship of the Channel Fleet and Dreyer, while continuing as the ship's gunnery officer, also acted as fleet gunnery adviser to Vice-Admiral Sir Arthur Wilson. Dreyer distinguished himself by placing the flagship first in Battle Practice and the Gunlayers' Tests for three years (1904-6) in succession: and his advice became so indispensable that, half way through his appointment, Wilson asked him to stay in *Exmouth* even though this meant declining an appointment (with good prospects of promotion) to the Senior Staff of *Excellent*.[6] In 1905, he was appointed to represent the C.-in-C. on the Gunnery Calibration Committee chaired by Rear Admiral Percy Scott.[7] Dreyer also found time to apply himself to theoretical gunnery questions, in 1906 contributing a paper on the proportion of short shots required to optimise the rate of hitting.[8] He continued to invent, but his proposals for improvements in telescopic sights (1903) and breech mechanisms (1907) were not adopted .[9]

[5] *Remarks on Admiralty Counter Statement to Rear Admiral Dreyer's Claim*, p.2 in DRYR 2/1.
[6] *Sea Heritage.*, pp.32, 45, 47-8, 52-3 and 57.
[7] 'Calibration of Guns. Report of Committee, &c' in ADM 1/7835, PRO. Dreyer, *Sea Heritage*,p. 45.
[8] Admiralty, *Half Yearly Summary of Progress in Gunnery, No.7, July 1906*, pp.80-84, AL: also referred to in DRYR 1/2 and 1/3.
[9] 'Dreyer's Inventions' (*op. cit.*). Secretary of the Admiralty to C.-in-C., Portsmouth, 1 July 1903 in DRYR 1/2. *Sea Heritage*, p.30.

APPENDIX XVIII

DREYER TABLES: TECHNICAL NOTES

I. POSITION FINDER FOR RATE

Clock Smoothing

Since the clock was set by a sequence of discrete rates, a graph of its ranges must have consisted of a series of straight-line segments. The slope of each segment was determined by the ranges at the start and end of the preceding segment: the slope (rate) equalling the difference between these ranges, divided by the segment duration. If the ranges had been entirely error-free, this might have approximated reasonably well to the underlying smooth curve. In practice, each range had a random error, while the intervals between ranges also fluctuated, adding to the uncertainties in the rates; thus the graph of clock range would normally have been even less smooth than that of the rangefinder ranges, as illustrated below.

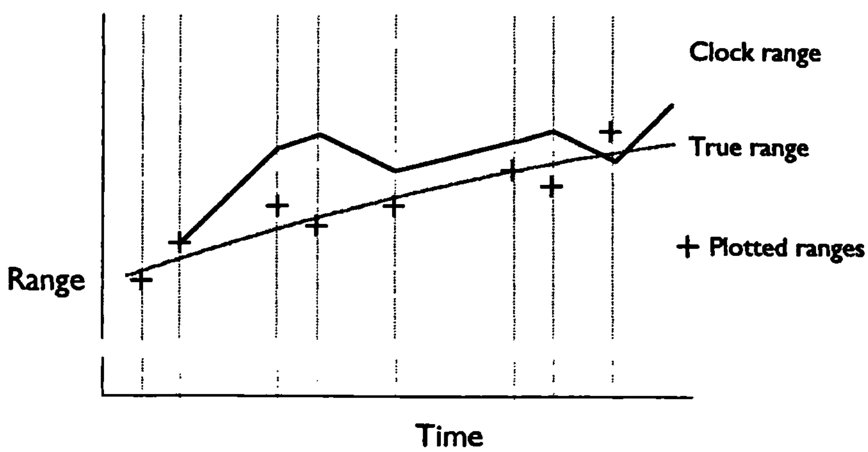

FIG. XVIII.1: PREDICTED CLOCK RANGES FROM POSITION FINDER RATES

While it might have been possible to reset the clock at the beginning of each segment to the latest range, this would have resulted in a 'sawtooth' graph of clock range which would have been even less smooth than that shown.

Type B Position Finder

In the Type B instrument, 'the moving paper need only be a quite narrow strip'. The inker was in a fixed position on the fixed bridge, over the strip. Initially, the moveable bridge was placed against the fixed bridge. When a new range was received, the inker placed a mark on the strip, while the travellers on both bridges were set to this range; thus the indicated rate was zero. The moveable bridge then followed the mark on the strip until another range was received. This was set on the traveller of the fixed bridge, while a new mark was made on the paper strip. The bar joining the two travellers indicated the instantaneous range-rate on the semicircular scale. As soon as the rate had been read off, it was reset to zero while the moveable bridge was returned close to the starting position so that it could follow the new mark on the paper strip.

The Dreyers recommended Type B when the traveller on the fixed bridge was not operated electrically from the rangefinder.[1]

2. VIRTUAL COURSE RANGE KEEPER 1908

John Dreyer described the instrument to Frederic in the hand-written letter accompanying his sketches (Plates 32 and 33).

> Observatory
> Armagh[2]
> 17/1/08
>
> My dear Fred
> Hope you can understand enclosed. I have had an awful rush to finish it for post.
> The black bar in (fig. 1) carrying pivot of range arm can be clamped in any position you like on table by the clamping gear. The relative bearing (I don't know if this is correct term; you have called it angle between Compass bearing & Virtual Course) is set on bearing plate & clock drive carries traveller along bar (X) fig. 1 at relative speed. The range arm is rove through the traveller & the range at any moment can be read off.
> I will think it over & write again tomorrow. I don't think it is really necessary to reverse movement of traveller along (X); it may however be convenient.

[1] F C and J T Dreyer, 'Position Finder for determining Rate of Change of Range' in RCAI Claims Files, T.173/91 Part III.
[2] The Dreyers' father, J L E Dreyer, was Director of the Armagh Observatory from 1882 to 1916: *DNB 1922-1930.*

> It would be advisable to have a clutch between endless screw (fig 2) & spur wheel (Y) to rapidly turn screw by hand.
>
> In haste
>
> Yrs
>
> J.T.D.

John described the action of the mechanism on a separate, undated sheet.

<u>Action</u>

> Set contact belt (h fig. 2) to relative speed. Unclamp clamping gear (fig. 1 & 3). Adjust range arm to range & relative bearing. Turn clamping handles thus firmly locking pivot of range arm. Start clock. The traveller will read the range on the range arm continually.[3]

If John Dreyer's Fig. 1 is compared to Fig. 2.6, it should be apparent that the range arm corresponds to SE, the distance from the pivot to the traveller being proportional to range R. The black clamping bar allowed the pivot to be positioned anywhere on the table, according to the initial range and the angle between the line-of-bearing and the virtual-course.

Someone involved with the RCAI hearings scrawled on the copy of Dreyer's sketch now in the PRO:

> Substantially the same as Pollen's Patent [?] of 1906.

Unfortunately, a copy of this patent has not been found, although Sumida has concluded that, like the later mechanisms outlined in 2,497/1908, it relied on simulating motion along a virtual course. However:

> Pollen's proposed device [of 1906] solved the problem posed by the non-existence of any motor whose speed could be varied continuously with precision...in such a way that a constant speed drive produced a variable speed result.[4]

Isherwood's testimony to the RCAI confirms that he rejected the use of a variable speed drive in the early clock designs.

> ...I was trying to devise some mechanism for running a certain thing at a varying rate. I found considerable difficulty in devising suitable mechanism for getting this varying rate, because I did not consider that the ordinary variable speed drive of a roller on a constant speed disc was suitable for the mechanism in which the rate was continuously changing.[5]

In contrast, John Dreyer did propose a variable speed drive, though of a different design comprising two cones, one driving the other through a friction belt sliding parallel to their axes. Since this was set to a speed proportional to the virtual speed, it did not vary while

[3] John to Frederic Dreyer, 17 January 1908 in T.173/91 Part III.
[4] Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) p.82.
[5] Isherwood before RCAI, Minutes of Proceedings, T.173/547 Part 15, pp.104-5.

both ships maintained constant speeds and courses; thus it was not subject to the concerns expressed by Isherwood. It should also be noted that, unlike the patent specification for 2,497/1908, John Dreyer's description and sketches do not indicate how the virtual course and speed was obtained. Presumably, the intention was to get it directly from a virtual course plot or from a Dumaresq.

The note on the sketch is correct only in that all these early range keepers worked on the general virtual course principles which had been embodied in the Dumaresq since 1902. To generate virtual speed, John Dreyer proposed a variable speed drive long before Isherwood accepted their use of such drives, initially in the Argo Clock Mark I.

3. TACTICAL PLOTTER

James Swinburne's review of the Dreyer and Pollen patents mentions, briefly, only one aspect of this invention.

> 20733/09
>
> Describes a cone variable speed gear apparatus. This patent is not of importance in connection with the present machine.[6]

Some further information was provided by Keith Elphinstone in his 1914 and 1916 reviews of patents.

> Patent 20733/09. Improvements in and relating to Apparatus for determining the positions of moving objects.
>
> One example of this Apparatus has been constructed by my Firm and was submitted for trial....[7]
>
> Patent 20733/08. [*sic*] Improvements in, and relating to Apparatus for use in controlling the fire of Guns.
>
> In connection with this Patent, a piece of Apparatus was constructed, consisting of Variable Speed Device with an Index or Pointer in the shape of a small bead which could be clipped to a string and caused to travel along a chart at any desired speed, and according to the relative position of the Instrument on the chart in any desired direction on the chart.
>
> Claim I. A pointer travelling in a pre-arranged direction at a variable Speed according to the Speed of a moving object.[8]

[6] *The Time and Range System. Report of J. Swinburne, F.R.S.*, 5 March 1913, p.3 in P.1024, AL.
[7] Elphinstone to Director of Navy Contracts, 18 March 1914, p.2 in 'Fire Control Apparatus: Various Patents', ADM 1/8464/181.
[8] 'Notes' 9 February 1916, p.2 with Elphinstone to Director of Navy Contracts, 14 February 1916 in 'Fire Control Apparatus: Various Patents' (*op. cit.*).

4. HYPERBOLIC CLOCK

Swinburne's report has three passages on Dreyer's 1909 clock patent.

> 21655/09
>
> A form of range-keeper....
>
> ....
>
> ...Dreyer arranges two bars...as embodied vectors, speed and direction of target, and speed and direction of own ship. This gives the speed and direction of target supposing own ship stopped. A range bar is set so that its length is the instantaneous range, and its direction that of the line of sight; it swivels at one end, and a screw moves the other grip, which is sliding, along it, so that this bar continues to gives [*sic*] instantaneous range as long as both ships preserve their speeds and courses.
>
> ....
>
> No. 21,655, 22nd September, 1909.– Patent for a range clock which, when set for course and speed of enemy, range and bearing of enemy, and speed of own ship, and started, will automatically transmit and continue to transmit the ranges to a receiver.
> A direct pinion drive variable speed drive was fitted.[9]

Elphinstone supplied further details.

> Patent 21655/09. Improvements in Range Keepers for use with Ordnance.
> One example of this piece of Apparatus has been constructed by my Firm and was submitted for trial....[10]
>
> Patent 21655/09. Improvements in Range Keepers for use with Ordnance.
> An example of this Apparatus was constructed by Elliott Brothers and was known as the T. & R.C.T. Instrument - it consisted of a Range Keeping Device depending upon the adjustment and relative motions of some elements and bars of which Own Course and Speed and Enemy's Course and Speed were among the number.[11]

At the 1925 RCAI hearings, Dreyer was cross-examined by Pollen's counsel about the reports written after the visit to Broadheath in July 1909.

> ...Then there are certain suggestions about the clock and you [Dreyer] apparently made a suggestion to them [Pollen and Isherwood] about what you called a hyperbolic clock of some kind. A. Yes.
> Q. I see the D.N.O. makes a suggestion that you should take out a Patent. A. But you will read, in fairness to me, what I said further down the page.
>
> ....
>
> ..."...an officer spoke to me some months ago of 'Mr. Pollen's hyperbolic clock' ....Mr. Isherwood stated that the great thing they had impressed on them...was that the apparatus should be easily capable of being set, or re-set should the data set for be shown by further plotting to be incorrect and this apparently led him to design his more complicated mechanism. No difficulty would however occur with the hyperbolic clock of the type I suggested as resetting it so as to give the new Virtual Course and Speed of Enemy and the new minimum range and range of the moment would set the Clock running correctly". That did not come to anything? A. I beg to be excused there; for the reason I put there [it is not clear what this refers to] nobody took it up.[12]

[9] Swinburne, *Time and Range* (*op. cit.*) pp.4 and 8.
[10] Elphinstone to DofC, 1914 (*op. cit.*).
[11] Elphinstone, 'Notes' 1916 (*op. cit.*).
[12] T.173/547 Part 17, p.61.

The above quotations give a consistent picture of the nature of the mechanism envisaged by Dreyer. The basic range-generator resembled John Dreyer's design of January 1908, though the means of clamping the fixed pivot of the range bar may have been different. In positioning the pivot, the mechanism was set for 'minimum range' as well as for 'range of the moment'; these must be, respectively, the R_0 and R shown in Fig. 2.6. The additions to the 1908 design were the two bars, representing own and enemy speeds and courses, from which the virtual course and speed were obtained; this was the same vector subtraction embodied in the Dumaresq. The virtual speed propelling the 'sliding grip' was obtained from a 'direct pinion drive'. This is the same term used for the drive which Dreyer mentioned as 'being made by Messrs. Elliott Bros.' in his 1910 'Remarks on Local Turret Control';[13] thus it appears that Elphinstone was correct in stating that one example was actually built. However, no record has been found of any trials; perhaps this provides further confirmation that the direct pinion drive was a failure, which in turn explains why this range-keeper did not come to anything.

Unfortunately, these straightforward conclusions are confused by Dreyer's subsequent answers to questions about the mechanism of the patented clock.

> Q. Was the idea...that you had a sort of master hyperbola? A. It is very difficult. I have forgotten a great deal of mathematics in the last 17 [*sic*] years; I have had other matters to attract my attention: but my recollection of it is that the idea one had of a hyperbola was that it was either a single hyperbola or a solid hyperbola....I cannot tell you at this period of time.
>
> ....
>
> Q. I am trying to assist your recollection. Mr. Pollen tells me that now that he has seen this document [the report by Dreyer and Craig] it all comes back clearly how this conversation arose. He says you suggested to him constructing a clock on the basis of the range hyperbola, and he pointed out that the slope of the hyperbola was different, and the difference was a function of the bearing rate; that is to say, in the one case your hyperbola would be comparatively flat and in another case it would be comparatively steep. A. Yes
>
> ....
>
> Q. He pointed this out to you, and said it was impossible to construct a clock on the basis of the time and range hyperbola; you had to have both rates, and he was at work on a clock to be used with the two rates, but was held up by the slipless drive. A. I can give you no help in the matter at all. There is my full report.

When Pollen was re-examined, he recalled:

> Captain [*sic*] Dreyer...suggested that if we engraved a plot with a hyperbolic curve...it should be possible to fix a running roller into this curve...and read off the change of rate [*sic*] by propelling those along sideways to follow this curve on the analogy of the snail

[13] 'Remarks on Local Turret Control by Commander F.C. Dreyer R.N....', 5 September 1910 in 'Local Control of Turret Guns. Special Firing carried out by HMS 'Vanguard'...' in ADM 1/8147.

> cam and other cams of that kind. We had some discussion about it and I could not get it quite clear between us that it was impossible to make a master hyperbola.
> ....I told him we had already been working for two years working out a rate clock that is running both rates, but we could not bring that up to perfection unless we had got rid of [*sic*] the slipless drive...and there we rested.[14]

It is apparent, firstly, that, in 1925, Pollen had forgotten the properties of the range-time hyperbola; as shown in Fig. 2.7, the slope (of the asymptotes) is proportional to the virtual speed (v), not the bearing rate. However, he was quite right that it was impossible to construct a single master hyperbola; whole families of curves would have been needed, for different values of v and R_0. Secondly, Pollen and his counsel were principally engaged in attempting to establish that Pollen had anticipated the Service system of plotting rates and setting them on a two-rate clock; their objective here was to show that, in July 1909, Dreyer was thinking on different lines. In fact, at that time, the hyperbolic relationship between range and time (when two ships were on steady courses) appears to have been comprehended correctly by both men:[15] and, although their mechanisms were very different, both Dreyer's patented design and the Argo Clock Mark I generated the full range of hyperbolic functions. However, it is unlikely that Dreyer would have revealed his own ideas to Pollen, but he could still have suggested the idea of a clock containing hyperbolic cams, while discussing possible alternatives to the Argo design. His reluctance to admit such a subterfuge may have been behind his recollection of a 'single or solid hyperbola'. If that memory can, for one reason or another, be discounted, the rest of the evidence indicates that the actual design contained no such element but was an elaboration of John Dreyer's proposal from early 1908.

5. LOCAL CONTROL INSTRUMENT

The 'Time and Range Chronograph, Range Clock & Transmitter combined'[16] brought together in one unit (Plate 35):

- a plotter with clockwork paper drive R
- automatic range plotting using an electrical receiver C from the turret rangefinder to position the range plotting pencil E (actuated by the rangefinder operator) by means of a long screw

[14] T.173/547 Part 17, pp.64 and 109.
[15] Pollen referred to 'the Dreyer bulk curves we had set out in the end of our "Reflections" pamphlet: T.173/547 Part 17, p.108.
[16] Dreyer, 'Local Control' (*op. cit.*).

- a sliding, rotating plate N with engraved parallel lines which could measure the mean slope (hence range-rate) from the rangefinder plot
- a gun-range scale T to which were attached all of the following:
- a clockwork range clock V with differential W for applying corrections
- a second long screw driving a gun-range pointer U: U carried a red pencil for plotting clock-generated ranges
- electrical transmission of gun-range J
- a rack-and-pinion worked by handle I by which T and all its attachments could be moved by an amount shown by the fixed pointer H on the spotting scale S.

While, even for local control, Dreyer held that plotting should be automatic, he also insisted that manual alternatives (handles X, Y and Z) were essential.

As described by Dreyer:

> The method of using the instrument is :-
> Start the clockwork R and commence taking ranges, the pencil E making a dot on the paper each time the Rangefinder Operator presses a key on taking a range. When a sufficient number of range dots have been made, measure their slope with N and set the rate read off at M on the clockwork V which should then be started.
> Then by means of the differential gear W bring U up in line with E, any spotting correction being put on at S with the handle I.[17]
> The gun ranges can now be read off the scale T opposite the pointer U and are transmitted by J.
> The gun ranges can kept tuned up to the Rangefinder ranges by turning W to keep U opposite E.
> ....
> <u>EXAMPLE</u> .:-
> Suppose the forecasted true range is 8000 yards (see diagram) and the corresponding gun range 8500 yards, then after an interval, ranges begin to come in again, and the mean range of these is 8400 yards.
> The operator should then turn W until U is in line with the mean position of E, thus increasing the gun range from 8500 to 8900 yards (This is a correction in range due to faulty rate and not an ordinary spotting correction due to differences between true and gun ranges).
> The operator immediately reports to the Officer of Quarters "I have upped 400". If the latter has just previously seen a shot hit, he may order "Down 400" to neutralize the above, which would be put on at the spotting scale S by turning I (the total correction at S being thus altered from "Up 500" to "Up 100"). U would then have to be run back by turning W to a gun range of 8500 to bring U back in line with E.
> If, however, the Officer of Quarters has <u>not</u> observed the fall of his last shot or two with any certainty, there can be no doubt that he should be guided by the new mean Rangefinder range and accept 8900 as the correct Gun range.[18]

[17] This initial 'spotting correction' must actually be the ballistic correction (to convert true-range to gun-range) put on in the manner of a spotting correction.
[18] Dreyer, 'Local Control', pp.18-9.

Although all circumstances (including the simple case of applying spotting corrections after opening fire) are not described explicitly, it appears that the instrument was used as follows.

Before opening fire.

Begin plotting ranges.

Set the total ballistic correction (for wind along, cordite temperature, time-of-flight, etc.) on the spotting scale S with handle I.

With the tuning handle of W, bring the gun-range pointer and pencil U opposite the mean rangefinder range as plotted by the rangefinder pencil E. Keep the gun-range pointer coincident with the latest mean rangefinder range.

The best estimate of gun-range is indicated by U and transmitted by J.

While firing.

The spotting scale S indicates the current best estimate of the difference between the gun-range and the true-range. Each spotting correction is applied by changing the indication of pointer H on S by the amount of the spotting order e.g. UP 200. Immediately after putting the spotting correction on S, use the tuning handle of W to bring the gun-range pointer back into coincidence with the mean rangefinder range; this transmits the spotting correction to the guns.

If the rate set on the clock is different from the rate of the rangefinder ranges, the two pointers will diverge. The gun-range pointer can be retuned to the mean rangefinder range with the W handle. This change will be transmitted to the guns. It must also be reported to the Officer of Quarters controlling the fire of the turret. If necessary, he can countermand it by ordering a opposite spotting correction; this is applied as normal, first on the spotting scale and then with the tuning handle.

6. BEARING TRANSMISSION IN *PRINCE OF WALES*

The following is an excerpt from the proposal accompanying Dreyer's letter to the DNO of 2 December 1910 (illustrated by Plate 37).

> FIG.I. shows diagramatically a case where ship's head is at 82° and bearing of target is 152°.
> Outside the Gyro Compass Receiver Card A, a Transmitter Ring B is mounted (see FIG.II). Between A & B is an Index Pointer C actuated by the Vanes used in connection with the Compass Receiver Card or if the latter is mounted inside a Rangefinder mounting, C moves with the rotating portion of the mounting carrying the

> Rangefinder.
> In FIG.II is shown the view of A, B & C obtained by an observer looking into the prism of the Gyro Compass Receiver card.
> The observer keeps the readings of B & A at C the same by turning the Transmitter handle D, which also transmits the bearing to which B has been turned, to a Receiver E on a Time and Bearing Chronograph.[19]

In fact, it was necessary that the Transmitter Ring B as well as the Index Ring C rotated with the vanes or the rangefinder. Then if, by rotating the transmitter handle, the graduations on B were brought back into coincidence with those on the Compass Card, the transmitter would transmit any change in compass bearing.

When bearings were transmitted from the rangefinder, the trainer would have been fully occupied keeping the target in the centre of the field of view of his telescope; an additional man would have been needed to work the transmitter handle in order to keep the scales on A and C in coincidence.

7. SEVEN PART RECORDER

The complete final sentence of the quotation in the main text from Moore's recommendation reads:

> It is therefore submitted that Messrs. Elliott Bros. may be requested to tender for five of the improved instruments omitting the gyro compass receivers.[20]

This appears to propose that the five improved tables should not be provided with gyro compass receivers. However, Elphinstone's description and schedules of the 'Seven Part Recorder' shows that this was not the intention.

The schedule of parts began with the standard parts I - X required for all variants of the design: that is, common components like the frame, motor drive (with hand alternative), range and bearing chronographs, range clock and Dumaresq. Optional parts included:

> XI. Gyro Compass Receiver complete with Dials for indicating Ship's Course, contact and Clutch device for controlling the movement of the Fore and Aft Bar of the Dumaresq (IX) with reference to the Compass Ring by means of a small Electric Motor; this whole equipment being mounted above the Dumaresq Instrument (IX).
>
> XII. Gear for setting a definite Rate of Change of Bearing on the Dumaresq IX [the bearing clock]...

[19] Dreyer to DNO, 2 December 1910 in T.173/91 Part III.
[20] DNO's Minute, 7 December 1911 in T.173/91 Part III.

XIII. Gyro Compass Receiver and attachment for transmitting "Compass Bearing" of Range Finder line of sight to Bearing Chronograph (IV) the Gyro-Compass Receiver being fitted in the R. F. mounting itself.

These modular parts were then included in a number of schedules for differently equipped ships. The five ships eventually provided with the Dreyer Tables Mark III were covered by:

SCHEDULE "A"

Equipment for a Ship fitted with Gyro Compass and Argo R. F. Mounting with Automatic Step by Step Transmission of Ranges and Bearings -
Parts I to XII inclusive to accomplish automatically the following:-

Plot Curve, Rate of Change of Bearing) for adjustment of
" " " " " " Range) Dumaresq
" " Ranges from Clock.
Adjust Fore and Aft Bar of Dumaresq Instrument for own Ship's Course.
Transmit Ranges from Clock to Receiver in Transmitting Station.

Note. - in the case of the Argo R. F. Mounting being controlled in Azimuth by the Gyro Compass, the Receiver for this part is not included in this Specification, being considered as a separate supply.[21]

Thus Moore was not recommending that the Mark III Tables (as they were to be known later) should be without gyro compass receivers. He was merely emphasising that only the receivers XI were to be included in the table order, while the receivers XIII were already included in the order for the Argo mountings for the five ships.

8. DUMARESQ MARK VI ON THE MARK III TABLE

In the standard Dumaresq Mark VI (as described in Appendix VII), the fore-and-aft bar was carried on a fixed outer ring. The compass ring turned between this outer ring and the instrument's bearing dial.

As modified for the Mark III Table, the bearing dial was fixed while the outer ring carrying the fore-and-aft bar revolved; as before, the compass ring also rotated. The compass ring was coupled to the bearing clock.[22] If the clock rate was set correctly by converting Dumaresq speed-across into bearing-rate, it generated change of target compass bearing $\Delta\chi$ (by integrating $\dot{\chi}$ as expressed by equation 2:9). Thus the compass ring turned relative to the fixed dial by $\Delta\chi$. Since the target bearing arrow indicated χ on

[21] Elliott Bros. 'Seven Part Recorder' revised 28 October 1911 in T.173/547 Part III.
[22] Commanders F C Dreyer and C V Usborne, *Pollen Aim Corrector System Part I. Technical History and Technical Comparison with Commander F.C. Dreyer's Fire Control System*, Gunnery Branch 1913, p.42 in P.1024, AL. *Handbook of Captain F.C. Dreyer's Fire Control Tables 1918*, C.B.1456, pp.17 and 49 and Plate 23, AL.

the compass ring, the bearing clock kept the target compass bearing correctly set as it changed due to the speed-across: provided that an increase in χ resulted in an *anticlockwise* rotation of the compass ring.

The compass ring also carried a circular rack which engaged with gears on the fore-and-aft bar. These gears were coupled through a flexible shaft to the relay motor controlled by the gyro compass receiver. The gear ratios were chosen so that the fore-and-aft bar rotated *clockwise* relative to the compass ring when own ship's compass course increased by $\Delta\kappa$. Thus the pointer at the fore end of the fore-and-aft bar correctly registered this change on the scale of the compass ring.

As can be seen in Fig. VII.1, this pointer also indicated the target bearing relative to own course, β, where:

$$\beta = \chi - \kappa$$

The indicated change in β ($\Delta\beta$) was positive when the fore-and-aft bar turned *anticlockwise.* Since the total rotation of the fore-and-aft bar was the sum of the rotations of the compass ring and itself relative to the compass ring:

$$\Delta\beta = \Delta\chi - \Delta\kappa$$

which is correct.

θ is the angle between the enemy bar and the fore-and-aft bar. Since::

$$\lambda = \theta + \kappa$$

and λ (enemy compass course) is assumed to be constant:

$$\Delta\theta = -\Delta\kappa$$

Thus the enemy bar and its compass ring were also geared to the shaft from the gyro compass relay motor such that it was rotated relative to the fore-and-aft bar by $\Delta\kappa$, in an anticlockwise direction when $\Delta\kappa$ was positive.

9. RELAY FOR ANSCHÜTZ GYRO COMPASS RECEIVER

The Dumaresq was driven through a flexible cable by a motor located behind and controlled by the Anschütz compass receiver. The control was effected by a device, then called a relay, which today would be described as a servo follower. The stepper motor in the compass receiver (itself connected to the master Anschütz compass) developed very little torque, sufficient only to rotate the compass card and a light contact arm. This arm rotated over an insulating disc carrying two semicircular arcs separated by two narrow gaps; the disc was rotated by the relay motor. When the gyro receiver and compass ring were reading identically, the contact arm lay exactly in the gap between the contact arcs. However, if the compass receiver then registered a change of course, the contact arm would rotate, thereby making contact with one or other of the arcs. This closed an electric circuit which, through an electromagnetic relay,[23] applied power to the motor with the polarity necessary to bring the gap once more under the contact arm. Hence the motor caused the compass ring to follow the receiver.[24]

This simple type of follower is another example of a 'bang-bang' servo. The motor is either off: or driving at full power in one direction or the other. Thus, if the compass was registering a slow turn, the motor would tend to follow in a series of jerks. Alternatively, a sudden big yaw would produce a large misalignment between contact arm and gap. In this case the motor ran up to full speed, until the contact arm once again reached the gap. However, the inertia of the motor and its mechanical load then tended to continue the motion; the contact arm overshot the gap, causing the motor to be powered in the opposite direction to overcome the inertia, change direction and once again return the arm to the gap. This cycle could repeat several times, with oscillations of decreasing magnitude, until eventually the motor settled down to a new static position. This characteristic behaviour is called hunting and it was observed in *Barham* by Midshipman Patrick Blackett; although his ship was fitted with a later mark of Dreyer table, it was initially provided with an Anschütz gyro compass installation. The amount of the hunting was enough to limit the usefulness of the bearing plot, though Blackett did not state its extent.[25] However, the accuracy of the plot was also restricted by the accuracy of the bearing transmitters, which used steps of $\frac{1}{4}°$. Thus the hunt would not have caused concern unless it was at least as great: i.e. at least $\pm\frac{1}{4}°$ around the nominal value shown on the receiver.

The errors caused by the fluctuations in the rates indicated by the Dumaresq can be calculated. For example, consider the error in speed-along, a.

$$a = e\ \cos\iota - s\ \cos\beta$$

$$= e\ \cos(\theta-\beta) - s\ \cos\beta$$

$$\frac{\partial a}{\partial\beta} = e\ \sin(\theta-\beta) + s\ \sin\beta = x \qquad \text{where x is speed-across}$$

[23] Meaning, in the modern sense, a switch operated by an electromagnet.
[24] See the *Technical Comparison* (*op. cit.*) Fig. V/9 for a schematic and circuit diagram.
[25] 'Rate of Change of Bearing Instrument' appended to P M S Blackett, 'Naval Diary 1914-1918', transcribed by and courtesy of Dr N M Blackett.

If a is in yds/min., x is in knots and a small change in β, $\delta\beta$, is in degrees:

$$\delta a = \frac{33.78\,\pi}{180}.x\,\delta\beta$$

Thus, for two 25-knot ships beam-to-beam on opposite courses, a change of ½° in bearing produces a speed-along (range-rate) error of 14.7 yds/min. Since this maximum value for the error is only a little more than half the step size for transferring range-rate to the clock, it is barely significant. In all other tactical circumstances, the error is negligible.

Similar equations can be derived for speed across. However, since, proportionately, larger steps are assumed for transferring speed-across, the hunt-induced errors can have had even less impact.

10. ELLIOTT STEP-BY-STEP MOTORS

While there is no doubt that the Original Table had three receiver motors, their supplier is not named explicitly in the sources. The letter from *Prince of Wales'* Captain Hopwood confirms that the rangefinder was fitted with the Barr and Stroud mechanism which ensured that, at all ranges, equal movements of the range adjusting head transmitted equal changes of range.

> Barr and Stroud's Automatic Range transmission.
> This mechanism is recommended for general adoption for present and future Barr and Stroud Rangefinders. It enables ranges to be more rapidly taken and communicated to the plotting chart and it saves the Range Taker the strain of reading off.[26]

Thus it is possible that Barr and Stroud step-by-step receiver motors were used on the table, even though they were designed only for driving digital receivers,[27] not plotter screws, let alone the differential gearbox and transmitting switch on the gun-range screw. However, the Royal Navy only adopted Barr and Stroud's complete auto-transmission gear on the introduction of their 15-foot rangefinders. Hence, alternatively, for *Prince of Wales* the Glasgow firm may have provided only the mechanically complex 'uniform range scale conversion gear' at the rangefinder:[28] while Elliott Brothers developed special receiver motors with adequate torque to drive the table screws. Later evidence relating to the Mark III Table indicates that this latter suggestion is the more probable.

[26] Hopwood to VAC Atlantic Fleet, 20 November 1911 in T. 173/91 Part III.
[27] Admiralty, Gunnery Branch, *Handbook for Fire Control Instruments 1914*, p.23, ADM 186/191.
[28] 'The Uniform Scale Auto-Transmission Gear' in Admiralty, Gunnery Branch, *Handbook for Naval Rangefinders 1921. Book I*, pp.101-7 (ADM 186/253) and *Book II*, Plates 57 and 57A (ADM 186/254). See also Michael Moss and Iain Russell, *Range and Vision* (Edinburgh, 1988) p. 88.

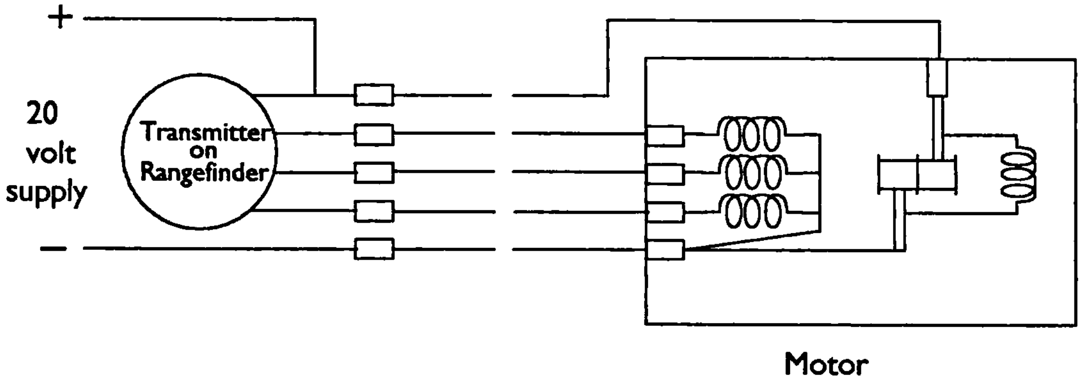

FIG. XVIII.2: ELLIOTT TRANSMITTER SWITCH AND RECEIVER MOTOR MARK III TABLE, 1913.

Fig. XIII.2 is redrawn from the connection diagram in the *Technical History and Technical Comparison*, Chapter V, Figure 9. It show that the range and bearing step-by-step receiver motors had three-phase stators and a wound rotor, apparently with simple slip rings. Unfortunately, the diagram gives no hints about the details of the transmitter switch.

In 1962, Hugh Clausen, the inventor of the M-type motor which had been widely used in British fire control systems between the Wars, wrote an account of this step-by step system. He also included a brief mention of some earlier designs, including those of Anschütz and Elliott Brothers.

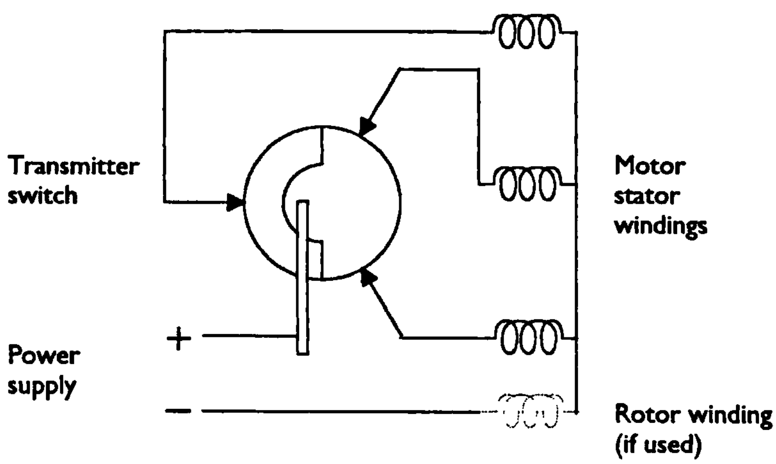

FIG. XVIII.3: ELLIOTT R-TYPE MOTOR

> The Anschutz step by step motor is a special case of one of the earlier types. It works on a 4-wire system , as shown in Fig. 1. [It was] made in a modified form by Elliott Brothers Limited as the R-type motor when they manufactured the Anschutz gyro compass in this country.
> This motor had a 3 phase stator like an M-type motor but the neutral point was brought out and used for the negative return, in series with a rotor winding fed through slip rings. The motor gives six steps per revolution...[29].

The main difference between the two schemes is that, in the Dreyer table, the rotor was connected directly across the supply, so its current did not change depending on whether one or two stator coils were energised. Although the details of its operation remain uncertain, there are sufficient similarities to suggest that Elliotts had developed both the receiver motor in the Original and Mark III Tables, and the R-type motors, from a common Anschütz original.

II. RATES OF CHANGE OF SPEED-ACROSS

1. The transfer and conversion of speed-across into bearing-rate on the Mark III Table was most difficult when the speed-across (x) was changing most rapidly i.e. when the rate of change of speed-across ($\dot{x}$) was:

a) at its maximum if $\dot{x}$ was positive

b) at its minimum if $\dot{x}$ was negative.

It is required to find the values of β and $\imath$ at which these 'turning points' occur.

2. In Fig. 2.6, let angle ESP be γ ($-90° < \gamma < 90°$). Resolve the virtual speed v along and across the line of bearing SE i.e. into speeds along and across. Thus:

$$a = v \sin\gamma$$

$$x = v \cos\gamma$$

$$\frac{R_0}{R} = \cos\gamma$$

From III:9 when courses are steady:

$$\dot{x} = -\frac{ax}{R} = -\frac{v^2}{R_0} . \sin\gamma \cos^2\gamma$$

$$\frac{d\dot{x}}{d\gamma} = -\frac{v^2}{R_0}(\sin\gamma . 2\cos\gamma . -\sin\gamma + \cos^2\gamma . \cos\gamma)$$

$$= -\frac{v^2\cos\gamma}{R_0}(\cos^2\gamma - 2\sin^2\gamma)$$

3. The two turning points are found where:

[29] H Clausen, 'Notes on Step by Step Transmission System' (Evershed and Vignolles Ltd. 1962), p.11, CLSN 1/7, CC. Fig. XVIII.3 is based on part of Clausen's Fig.1.

$$\cos^2\gamma = 2\sin^2\gamma$$

$$\tan\gamma = \pm\frac{1}{\sqrt{2}} = \pm 0.707$$

Thus: $\gamma = \pm 35.26°$

4. With two ships on opposite courses, $v = e + s$ and $\gamma = 0°$ when the ships are beam-to-beam. When the target is ±35.26° before or abaft the beam, $\dot{x}$ is most rapid. For 25-knot ships that pass at 8,000 yards:

$$\dot{x}_{max} = \mp\frac{50^2 \times 33.78 \times \sin 35.26 \times \cos^2 35.26}{8000} = \mp 4.06 \text{ knots/min.}$$

Thus the minimum time to change by 2 knots is 29.6 seconds.

5. In equation III:10, the second term gives the rate of change of speed-across due to change of course. This rate is at a maximum when the target is dead ahead or astern; for a 25-knot ship turning at 20°/min., it evaluates to ±8.73 knots/min. If both terms had the same sign i.e. the rates of change were additive, it would probably have been easier to alter the bearing-rate every time the speed-across changed by 4 knots i.e. every 18.8 seconds.

12. BEARING AND RANGE-RATE ERRORS

As shown in Note XVIII-9:

$$\frac{\partial a}{\partial \beta} = x$$

Thus a small error ε_β in β will result in an error in speed-along of:

$$\varepsilon_a \simeq x.\varepsilon_\beta$$

To obtain ε_a in yds/min. when x is in knots and ε_β is in degrees, use:

$$\varepsilon_a \simeq 33.78\, x.\varepsilon_\beta.\frac{\pi}{180} = 0.5896\, x.\varepsilon_\beta$$

When courses were similar (see the Jutland examples in Chapter 2), x was less than 10 knots, so a 5° error in bearing would result in a range-rate error of only about 25 yds/min. This would be increased five-fold for two 25-knot ships on opposite courses.

13. THE ARGO CLOCK MARK IV IN THE DREYER TABLE MARK II

The handbook for the Argo Clock Mark IV was dated 10 January 1914. Yet it contains no indication of how it was to be used in conjunction with Dreyer-type rate plotters.[30] Further, although 'early in 1914', *Queen Mary* already had Elliott-designed

[30] Gunnery Branch, *The Argo Range and Bearing Clock, Mark IV*, 10 January 1914, AL.

follow-the-pointer transmitters,[31] the arrangements for transmitting gun-range described in the handbook are different. These have already been explained in Note XII-12. Despite the automatic operation of the clock (when own course was steady), spotting corrections could not be transmitted to the guns without an operator following a pointer; thus the transmission arrangements were little better than with the Elliott gear, where all changes of range were transmitted by following a pointer.

As arranged according to the handbook, neither of the shafts emerging from the Argo Clock Mark IV were suitable for driving the transmitter-switch to the clock-range pencil of the Dreyer range-plot. The shaft to the transmitter-switches and the black N pointer rotated, in effect, according to the change in gun-elevation: and it did not respond to spotting corrections set with handle H1. In contrast, the shaft connected through the cams and gearbox to the red M pointer did make equal turns for equal changes in range: but it registered gun-range rather than the true-range required by the plot. This shaft was driven by a differential coupled to both the range-clock (Drive I) and the range-tuning handle H2. However, the standard Dreyer range plotter already had its own spotting differential gearbox. Thus the simplest arrangement would have been to connect the clock-range transmitter-switch to the M-pointer shaft: and leave the spotting correction always at zero on the Argo clock.

Another flaw in the Argo design was that the clock-range could only be tuned with handle H2 by disconnecting the variable-speed drive I; especially when the range-rate was high, a significant change of range could be lost while the handle was being manipulated. If the spotting corrections were now to be applied at the plot, the redundant spotting differential in the clock could be used for clock-tuning. The clock-range (predicted true-range) would then have been indicated by the pointer labelled GUN RANGE: though it would probably have been easy enough to remove it and replace it with the RANGE FINDER pointer, which would no longer have been required in its original position. These simple modifications should have been well within the capabilities of the dockyards, so they could have been made after the clocks were delivered from Argo.

An objection to this suggestion is that the main reason for the unsatisfactory arrangement described in the handbook appears to have been to avoid the additional load

[31] Elphinstone, 'Notes' 1916, p.4.

of a transmitter-switch on Drive I. If the switch was left connected to Drive IV, it would have been necessary, in effect, to connect together the roller-carriages of Drives I and IV: but also to add new differentials or clutches so that tuning corrections were applied equally to the outputs of Drives I and IV. Such extensive modifications are much less probable.

While the clocks could have been altered to meet the new requirements, these conjectures still do not explain why the handbook describes the clock as coupled directly to unequal-step transmitters. By the publication date, the Argo Company were already selling abroad and needed just such a transmission scheme, without any intervening rate plotter. Perhaps, therefore, the handbook was largely prepared by the firm. Since they had been struck from the list of approved suppliers, the Admiralty would certainly have gone to considerable lengths to keep secret how the Argo clocks were being adapted to Dreyer-type plotting. On the other hand, the handbook was evidently not revised before being printed by Eyre and Spottiswoode, apparently as normal.[32] Perhaps, with only five ships affected, a revision was not thought worthwhile.

Unfortunately, unless new evidence emerges, the final form of the Argo Clock Mark IV in the Dreyer Table Mark II must remain conjectural: though the simple re-arrangement proposed above does seem the most likely. The Argo clocks were probably modified by the Dockyard, using parts supplied by Elliotts, as they were delivered from Argo during 1913. *Conqueror* was commissioned in November 1912, so her table must have been installed later. *Ajax*, *Centurion* and *Audacious* followed in March, May and October 1913, respectively, so some could have received their fire control tables before they were commissioned.[33]

14. DREYER'S 'AUTO RATE' APPARATUS

As can be seen from Plate 45, the two 'sliders' which moved in response to any changes in Dumaresq rate were constrained to move orthogonally by the pinions engaging in the fixed racks. Each slider carried a transmitter-switch; the commutator rotated with one of the pinions, while the contacts were held fixed. Thus a switch transmitted movements of its slider to the connected motor.

[32] The printers mark on p.3 reads '*E* (33)19331 Pk538 125 2/14 E & S'. The author is grateful to Prof. Sumida for explaining the significance of these marks.
[33] Oscar Parkes, *British Battleships* (London, reprinted 1990) pp.521, 528 and 538.

The range-rate motor was coupled directly to the roller of the range-clock. This arrangement was mathematically correct. However, it is most unlikely that a stepper-motor could have developed enough torque to drive the roller sideways against the considerable friction needed to prevent significant slippage in the range-clock.

The bearing-rate (more correctly, the speed-across) switch was wired to a motor driving the cone of a cone-and-roller variable speed drive. Its roller was positioned (although the means were not shown) by the range-clock. The roller's shaft worked another transmitter-switch, while its motor was supposed to set the rate of the bearing-clock. The cone rotated only when there was a change of speed-across (δx).[34] This generated a change in the bearing-rate of R δx i.e.

$$\delta\dot{\chi} \propto R\,\delta x$$

But, from III:2:

$$\dot{\chi} = \frac{x}{R}$$

Thus Dreyer's first, elementary mistake was to multiply, not to divide, by R. Perhaps he had misdrawn the variable-speed drive and really intended to show the cone-and-roller 'in reverse' (as in the Argo Clock Mark III) to get:

$$\delta\dot{\chi} \propto \frac{\delta x}{R}$$

However, this would still have been incorrect because, in fact:

$$\delta\dot{\chi} = \frac{\delta x}{R} - \frac{x}{R^2}.\delta R$$

Elphinstone saw clearly what was wrong with Dreyer's proposal.

> ...assuming that a certain...deflection is adjusted on the Dumaresq dial...any subsequent alteration of the Range would only cause [the] Roller to travel longitudinally on the shaft...and no alteration to the Rate of Change of Bearing... would result, which I do not think is correct.
> The Device appears to me to call for a system of proportional levers whereby alteration to <u>either</u> the deflection <u>or</u> the Range alters the Rate of Change of Bearing.[35]

15. EXPECTED ADDITIONS TO THE DREYER TABLE, FEBRUARY 1913

At the beginning of 1913, Dreyer and Usborne were concerned to emphasise all the positive features of the Dreyer Tables and, in the *Technical History and Technical Comparison*, were none too scrupulous in distinguishing between existing features and those

[34] Dreyer to DNO, 19 December 1912 in T.173/91 Part III.
[35] Elphinstone to DofC, 1914, sheet 4.

envisaged for the next model, that which became the Mark IV. Nevertheless, in his 1913 Addendum, Dreyer did provide a clear statement of intent.

> For all future supplies of these instruments, the following additional parts have been designed and will probably be included:–
> (i) Automatic attachments, which, *when clutched in,* will automatically keep the Dumaresq adjusted for the Bearing of the Enemy, and also automatically keep the pointer of the roller of the Range Clock in line with the bows of the enemy ship, as the latter moves over the central disc of the Dumaresq.
> (ii) A corrector which will automatically allow for the "slip" of own ship when turning.
> (iii) A connection from the Dumaresq of the instrument actuating a repeat dummy enemy's ship on the Control Officer's Dumaresq, thus showing on the latter the course and speed of enemy set on the former. Also a Range Rate Receiver alongside the Control Officer's Dumaresq, operated automatically from the Instrument.
> (iv) A "Gun Deflection Drum" added to the "Time and Bearing" Plot.
> (v) Automatic Range Transmission from the Instrument to the Gun Positions.
> (vi) A "Time of Flight" corrector to allow for change of Range in the Time of Flight.
> (vii) The Time and Range plot will have arrangements added to enable the results of several Range Finders to be plotted.[36]

However, only some of these features were actually incorporated in the Mark IV.

(i) The new Electrical Dumaresq, with the Change-of-Bearing gear, automatically set the rates on the range and bearing clocks, but it was nothing like Dreyer's proposal of December 1912.

(ii) A single example of the slip corrector, which introduced a lag of 10°, had been ordered for the first Mark IV table, for *Iron Duke.* In July 1914, it was decided that it should 'not be introduced without further experiments'.[37] Thereafter, it disappears from the record; presumably under wartime pressures, the need for this elaboration never became sufficiently urgent for the experiments to be renewed.

(iii) Commutator-switches were incorporated in the Electrical Dumaresq to transmit enemy speed and inclination and the rate to the gun control tower. However, all these data were displayed on a single Repeater instrument rather than on the control officer's Dumaresq.[38]

(iv) The Mark III table had a 'Dumaresq Deflection' drum which converted between bearing rate and speed-across. This was retained in the Mark IV, mainly for converting

[36] *Technical Comparison,* pp. 47-8.
[37] DNO's Minute 'Dreyer Fire Control Apparatus', 6 July 1914 in 'Important Questions dealt with by DNO', Volume III, 1914, p.617.
[38] *Handbook 1918 (op. cit.)* p.76 and Plates 25 and 33

the bearing rate measured off the bearing plot. A second drum was also fitted to convert from bearing rate to Gun Deflection i.e. the units of deflection used on the gun sights.[39]

(v) Range transmission to the guns was not made fully automatic and continued to rely on an operator following a pointer.[40]

(vi) The tables do not seem to have been given their own time-of-flight corrector; instead, this and other range corrections were obtained from the range-corrector instrument invented by J T Dreyer in 1908.[41]

(vii) The abandonment of the Macnamara automatic plotter in favour of the simple Brownrigg keyboard is described in the main text.

16. AUTOMATIC AND MANUAL PLOTTING

Marks II and III

In the *Technical History and Technical Comparison*, Dreyer described how ranges from the Argo mounting were plotted automatically on the Mark III: while, as an alternative, ranges from another rangefinder (on a Barr and Stroud mounting) could be plotted manually. As rangefinder control was developed, it became usual to plot ranges from multiple rangefinders, those from the Argo mounting automatically, those from Barr and Stroud mountings manually.

Ships with 13.5-inch guns had Barr and Stroud Mark II* transmitters and receivers, and buzzers to signal new ranges.[42] As soon as the range-taker made a 'cut', he called the new range to the transmitter man, who set the new range on the transmitter and pressed the buzzer key. At the sounding of the buzzer in the TS, the range plotter quickly drew a short line on the plot using the edge of the range scale. Since the actual range on the receiver then remained unchanged until the next cut was made, there should normally have been enough time to read off the range and mark it on the line, as a dot surrounded by a circle.[43]

[39] Elliott Brothers, London, 'Captain F.C. Dreyer's Fire Control Apparatus Mark IV*. As fitted in H.M.S. Royal Oak', May 1916, sheet 44 and Fig.XII, *Excellent* Historical Library.

[40] *Handbook 1918*, p.72 and Plate 31.

[41] *Technical Comparison*, p.47. The 'Dreyer Calculator' was still used in 1930: see 'Pamphlet on the Dreyer Tables Mark III*, 1930' (p.3 and Plate 1) and 'Pamphlet on the Dreyer Tables Mark IV*, 1930' (p.7 and Plate 2) in 'Guard Book for Pamphlets on Dreyer Tables', AL.

[42] *Fire Control Instruments, 1914* (*op. cit.*) pp.24-5 and Plate 68.

[43] *Technical Comparison*, p.44. Perhaps the ranges were written down in the order in which they were received; it should have then been a simple matter to plot each in turn on the next unused time-line.

The original plotting arrangements on the Mark II Tables were probably the same as for the Mark III.

The rangefinder screw used for plotting Argo ranges may have interfered with the mechanism of the Brownrigg keyboards, in which case the screw and receiver motor would have been removed when the keyboards were fitted. However, assuming the keyboards plotted by perforating the paper from below, it may have been possible to retain automatic plotting when the new method of manual plotting was introduced. The keyboard (and the later typewriter) should have allowed the ranges to be recorded much more quickly and accurately than before. However, timing accuracy depended on positioning the carriage and pressing the right key as quickly as possible after a buzzer sounded.

If the plan views of the Mark III Table from 1913 and 1918 are compared,[44] it looks as though the later gun-range screw was in the same position as the earlier rangefinder screw. If the latter had already been removed, it would have been necessary to refit a new screw in the old position. If, until then, automatic plotting of Argo ranges had been retained, the range receiver motor would have been removed when the screw was reconnected (through a flexible shaft) to the output shaft of the spotting differential. Thus automatic range plotting definitely ceased once the gun-range screw was introduced.

*Mark IV**

In the 1916 pamphlet describing the Mark IV* Table supplied to *Royal Oak*, the only means for plotting ranges was the Brownrigg keyboard. The 15-foot rangefinders of 15-inch ships were all on Barr and Stroud mountings and they were equipped with a new type of Barr and Stroud transmitter and receiver, the Mark III.[45] At the rangefinder, the rangetaker no longer had to call the ranges; as he adjusted the cut, 'uniform range scale gear' converted between the reciprocal scale of ranges of the rangefinder and the uniform (linear) scale of the transmitter dial; thus a pointer on this dial always indicated the actual rangefinder range. On obtaining a cut, the rangetaker pressed a foot-pedal to actuate a 'cut' indicator on the transmitter dial. The man at the transmitter immediately worked his transmitter-handle to bring a follow-up pointer into alignment with the new range. As soon as the transmitter handle was moved, a shutter closed over the range previously

[44] *Technical Comparison*, Fig.V/7 (Plate 41) and *Handbook 1918*, Plate 40.
[45] *Fire Control Instruments 1914*, p.25 and Plate 69. *Annual Reports of the Torpedo School, 1914*, p.74 and *1915*, January 1916, p.228 in 109M91/ART 2, HRO.

indicated at the range receiver; by means of a switch, the transmitter man could open the shutter to reveal the new range as soon as it had been transmitted. Thus the range remained unchanged on the receiver from one 'cut' to the next, which provided as much time as possible to record it on the plot.[46]

When a gun-range screw was added to these tables, a new fitting must have been required.

Mark IV

There is no reason to suppose that, apart from its width, the range plot on *Queen Elizabeth's* Mark IV Table was any different from the later Mark IV*s. Further, the only method of plotting ranges shown in the general view of the table in the 1916 pamphlet is the Brownrigg keyboard. This figure is captioned:

> Captain Dreyer's Fire Control System Mark IV.
> H.M. Ships Iron Duke & Class and Tiger.
> Elliott Brothers London. 17.8.14[47]

Thus it appears that, in these ships, ranges received from Argo mountings were plotted manually, not automatically. However, it is uncertain how long the Argo mountings were retained in these ships.

In each ship of the earlier *Lion* and *King George V* classes, the Argo mounting was placed under an armoured hood revolving on top of the conning tower; the hood and the armoured partition separating the mounting from the rest of the conning tower was known as the Argo Tower. The hood was trained by electric motors but the control switches supplied by Argo, which enabled the hood to follow the rangefinder, were unreliable. In October 1913, it was decided that, for the *Iron Duke* class and *Tiger*, the rangefinder hood should be trained hydraulically. In these ships, the hood was on top of the squat Gun Control Tower (GCT), which protruded above the roof of the conning tower.[48] A memorandum of August 1914 concerning the breakdown of *Lion's* 'Argo Revolving Hood' during the action in the Heligoland Bight confirmed that the hoods in the ' "IRON DUKE" Class are fitted with hydraulic training'.[49] *Tiger's* Jutland reports

[46] *Handbook of Range-Finders and Mountings 1921* (*op. cit.*). In later installations, the shutter was replaced with a lamp illuminating the word 'cut' at the receivers.
[47] 'Dreyer's Apparatus Mark IV*', 1916 (*op. cit.*) Fig.1.
[48] Admiralty to C.-in-C. Home Fleets and Admiral Superintendent , Portsmouth, both 21 September 1913 with extracts from reports by Commanding Officers of *King George V* (2 June 1913) and *Lion* (22 May !913. Ships' Cover 268A/8, *Iron Duke* Class, NMM. John Brooks, 'The Mast and Funnel Question' in John Roberts (ed.) *Warship1995* (London, 1995) pp.50-1.
[49] DNO's memorandum, 8 September 1914 in 'Cruiser engagement in Heligoland Bight 28 August

mention the Argo rangefinder, though they do not explicitly state its location; they also imply that it was not used as a source of bearings for her Mark IV Dreyer Table.[50]

By 1921, the *Lion* and *King George V* classes still had 9-foot FQ2 rangefinders on Argo mountings in their 'Argo Towers'. All the ships with revolving hoods also had 15-foot FT24 rangefinders installed in light housings attached to the rear faces of their hoods; the supply of rangefinders for this purpose had been approved in October 1916.[51] Yet even the term 'Argo Tower' does not appear in the lists of rangefinders fitted in the *Iron Duke* class and *Tiger*. Nonetheless, *Tiger* still had her Argo mounting, though it was now in the fore-top and carried a 12-foot FQ2 - this was probably the 'long rangefinder' installed aloft in 1918;[52] a 9-foot FQ2 remained in the GCT, but now on an MP2 mounting. No Argo mounting appears in the list for the *Iron Dukes*; instead, a 9-foot FT8 (a more modern design than the FQ2) was installed 'inside' the GCT on a turret-type MG3 mounting.

The ships of the *Orion* class also retained their Argo mountings in the original position aloft: though, as in *Tiger*, they had been adapted to the 12-foot FQ2.[53] Clearly, the Argo mounting, with or without an electrically-trained hood, was still giving good service. Yet it had been removed from the GCTs of ships with hydraulically-trained hoods. Perhaps the hydraulic control, which was intended to enable the armoured hood to follow the training of the Argo rangefinder, proved in service to be unsatisfactory in some way; if it became necessary to resort to manually-controlled training, the rangefinder had to follow the hood, for which the Argo mounting was unsuited. Alternatively, when the 15-foot rangefinder was installed on the back of the armoured hood, it may have been decided to revert to manual training and transfer control to the operators of what was now the ship's principal rangefinder. In either case (or even both), the alterations were probably made when the 15-foot instruments were fitted i.e. after October 1916. The decision to order 12-foot rangefinders for installation in fore-tops was not taken until November 1917,[54] which is consistent with the date for the alteration to

1914...', ADM 1/8391/286.

[50] H.M.S. "TIGER", 'Gunnery Records during Action of 31st May 1916' and 'Gunnery Report' 30 October 1916 in ADM 116/1487.

[51] Enclosure with Admiralty to C.-in-C., 10 October 1916 in 'Committees formed to consider experience at Jutland, ADM 137/2027.

[52] Parkes, *British Battleships* (*op. cit.*) p.554.

[53] *Handbook for Rangefinders and Mountings 1921, Book I*, Appendix III, p.168. The author is grateful for this reference to Mr. John Roberts.

[54] Admiralty, Technical History Section, *The Technical History and Index*, 'Fire Control in H.M. Ships',

Tiger's fore-top; however, the 15-foot rangefinder had been fitted before this work was done,[55] so it is even possible that the Argo mounting was removed and later reinstated aloft.

While the precise chronology remains obscure, the available evidence suggests that the Argo mounting was not used as the source of bearings for the Mark IV Dreyer Tables in the *Iron Duke* class and *Tiger*. Until Jutland, the mounting was one source of manually plotted ranges but, by the end of the War, only one remained, in *Tiger's* fore-top.

17. CHANGE OF BEARING GEAR

In both the Argo Clock Mark V and the Dreyer Tables Mark IV and later, a proportional lever and spiral cam were used to convert speed-across into bearing-rate. The different mechanisms are shown in schematic form in the following figure.[56]

In the diagrams overleaf (see also Plates 29 and 48), y represents the displacement caused by a spiral cam. To produce the correct displacement, the cams in the two mechanisms had to be cut to quite different functions of the range, R. Let Y represent the fixed dimension which determines the size of the mechanism, x represent the displacement proportional to speed-across and $\dot{\beta}$ the required displacement proportional to bearing-rate. If k and k′ are constants of proportionality:

Dreyer

$$\frac{\dot{\beta}}{x} = \frac{y}{y - Y} = \frac{k}{R}$$

$$Ry = kY - ky$$

$$y = \frac{kY}{k + R}$$

Argo

$$\frac{\dot{\beta}}{x} = \frac{y}{Y} = \frac{k'}{R}$$

$$y = \frac{k'Y}{R}$$

Since Argo patent 16,373 claimed only for 'cam-operated means for obtaining...a displacement proportional to $\frac{1}{R}$', Elphinstone's design did not infringe it. However, could he have obtained the broad principle from the Argo patent: or even set out to avoid it?

The Argo patent was applied for, with a provisional specification, on 16 July 1913; the complete specification was left on 16 January 1914. In February 1914, the Admiralty had asked the Patent Office for notice of Argo patents as soon as they were

---

December 1919, pp.33-4, AL.

[55] John Roberts, *Battlecruisers* (London, 1997): compare photographs on pp.39 and 119.

[56] *Handbook 1918*, pp.61-2 and Plate 27. Argo patent 16,373/1913, Fig.2.

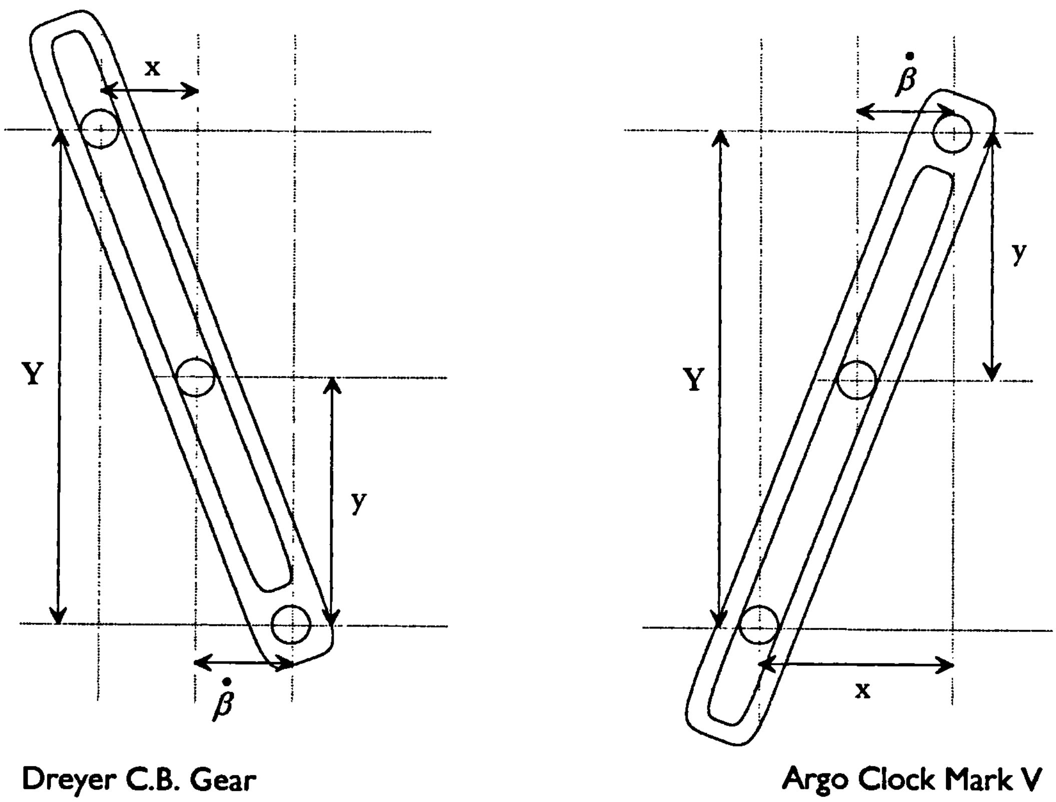

FIG. XIII.3: SPEED-ACROSS TO BEARING RATE CONVERSION

submitted. This request had been refused, the Patent Office insisting that patents remained confidential until they were accepted and published;[57] however, they did undertake to supply copies of Argo patents as soon as they were published.[58] 16,373/1913 was accepted on 16 July 1914. Thus even if it had been published immediately,[59] it could not have reached the Admiralty until after the first Mark IV table had been completed.

In March 1914, at the request of the Director of Navy Contracts, Elphinstone made some suggestions concerning patent cover for the existing and new Dreyer Tables. Dreyer had already submitted a complete patent specification which included his spurious

[57] For the Patent Office's insistence on preserving the confidentiality of unaccepted patents, even during the Great War, see T H O'Dell, *Inventions and Official Secrecy* (Oxford, 1994) p.71. The author is most grateful to Dr Anita McConnell for this reference.

[58] DNO's minute, 'C.P. 11614/13. Pollen Patents; Question of Civil Proceedings Against Argo Co.', 2 February 1914 in 'IQ/DNO, Vol. II, 1913'. *Pollen Aim Correction System. General Grounds of Admiralty Policy and Historical Record of Business Negotiations*, February 1913, Annex p.9, P.1024, AL.

[59] This seems to have been the usual procedure. Two of Pollen's other patents, 23,352 and 25,768 of 1912, were accepted in December 1913 and marked as printed in the same month. The print date on 16,373 is just '1914'.

proposal from the end of 1912,[60] but Elphinstone realised that it was not correct and what was needed in its stead.

> The Device appears to me to call for a system of proportional levers whereby alteration to either the deflection or the Range alters the Rate of Change of Bearing.

He described the scheme he then adopted as 'a special application of a Device which has been used for a long time for a particular purpose'.[61] Although Elphinstone mentioned another Pollen patent in his letter,[62] he did not refer to 16,373/1913. However, a copy had evidently reached the Admiralty by August, when a minute by the DNO (Captain Singer) suggested, optimistically, that it had been anticipated by Dreyer's erroneous 21,480 of 1912.[63]

When the subject of patent cover was raised again in 1916, Elphinstone specifically drew 'attention to Mr. A.H. Pollen's Patent 16373/13, Claim I, where Apparatus is mentioned on lines somewhat similar to that [used in the] Tables, Mark IV and IV*'. He went on to propose that, although the device actually adopted was 'a special application of a known mechanical method [it] might possibly be worth protecting'.[64]

Dreyer, on the other hand, took the view that it was 'too late to take out a New Patent...as it would be invalidated by Mr. Pollen's Patent...16373'.[65] However, in early 1916 Dreyer was attempting to secure an award from the Ordnance Council for 'his' tables. On 1 February 1916, he declared:

> In the case of each of the inventions described in [my] patents, I took out a provisional specification...before communicating with the Firm, so that the prior claims of the Admiralty should be clearly established.
> The actual details of such machines when made are of little importance, and could be designed by any good Firm of Instrument Makers to whom the invention was communicated.[66]

He was awarded £5,000 on 10 February:[67] but this did not persuade him to give any more credit to Elphinstone.

[60] Secret patent 21,480, applied for 20 September 1912. The provisional specification was mainly concerned with 'the control of own ship's bar by the gyrostat compass': Swinburne, *Time and Range*, pp.4 and 8 (the number and date on p.8 are incorrect).
[61] Elphinstone to DofC, 1914, pp.4 and 6. Unfortunately, there are no clues to what was 'the particular purpose'.
[62] 2,497/1908, published with the other withheld Argo patents on 6 November 1913.
[63] DNO's Minute, 18 August 1914 quoted in Admiralty to C.-in-C. Home Fleets, 1 March 1916, ADM 1/8464/181.
[64] Elphinstone to DofC, 1916 (*op. cit.*) and Elphinstone, 'Notes', 1916, p.7.
[65] Enclosure (b) with Dreyer to C.-in-C. Home Fleets, 7 March 1916 in 'Fire Control, Various Patents'.
[66] Dreyer to C.-in-C. Home Fleets, 1 February 1916 in 'Fire Control, Various Patents'.
[67] 'Extract from Recommendations of the Admiralty Members of the Ordnance Council at a Meeting 10.2.16 concerning Dreyer's award': Dreyer to Vice Admiral Sir Frederick Field, 12 November 1923: both

> The fact, as mentioned by Mr. Elphinstone, that in my Secret Patent No. 21,480 of... 1912, the example quoted...is not quite automatic, is unimportant.[68]

At the RCAI hearing in 1925, Dreyer was seeking a further award and was only prepared to acknowledge Elphinstone's 'assistance' in elaborating the plans for the first table: although he was obliged to admit that he had had no part in devising the 'poached egg'.

> The designers chose to suggest another method; but I think that is only a detail.[69]

Thus, in both 1916 and 1925, Dreyer had ulterior motives for denigrating Elphinstone's innovations, even if this meant accepting that Elliotts had been anticipated by Argo. In fact, while Isherwood was certainly the first to use a lever and cam, there is nothing to suggest any direct influence on Elphinstone. Both engineers made independent and significantly different use of a long-known mechanical principle.

18. Completion Dates for Ships with Tables Mark IV and IV*

Year	Quarter	Ship	Completion Date	Dreyer Table Mark
1914	April - June	*Marlborough*	June	I
	July - September	*Iron Duke*	August: see Note.	IV
	October - December	*Benbow* *Tiger* *Emperor of India*	October October November	IV IV IV
1915	January - March	*Queen Elizabeth* *Warspite*	January March	IV IV*
	April - June			
	July - September	*Canada*	September	IV*
	October - December	*Barham*	October	IV*
1916	January - March	*Malaya* *Valiant* *Revenge*	February February March	IV* IV* IV*
	April - June	*Royal Oak* *Royal Sovereign*	May May	IV* IV*
	July - September	*Repulse* *Renown*	18 August 20 September	IV* IV*
	October - December	*Resolution*	December	IV*
1917	January - March	*Courageous* *Glorious*	January January	IV* IV*
	April - June			
	July - September	*Ramillies*	September	'V'

in DRYR 2/1.

[68] Dreyer to C.-in-C. 7 March 1916 (*op. cit.*).

[69] Dreyer before RCAI, T.173/547 Part 16, pp.83 and 85. Argo patent 16,373/1913 was not considered by the Commission.

Note. With the exception of *Iron Duke* (against which is the earliest date for the installation of the first Mark IV Table), the dates in the table are the ship's completion dates given by Parkes in *British Battleships*.

The 1918 *Handbook* lists the ships with Mark IV* tables in the following order.

Resolution, Revenge, Royal Oak, Royal Sovereign
Barham, Malaya, Warspite, Valiant
Canada
Renown, Repulse
Lion, Princess Royal
Courageous, Glorious[70]

Thus, by the last year of the War, *Lion* and *Princess Royal* had Mark IV* tables. No explanation is apparent for the 'R'-class appearing first in this list but, even so, it still suggests that the two older battlecruisers were not re-equipped until near the end of the production run for the Mark IV*. This would also be expected from the completion dates, which show that demand for new ships was beginning to fall off by the end of 1916; manufacturing capacity was then available for delivery of the replacement tables, perhaps in the second quarter of 1917.

19. JUTLAND REPORTS

New Zealand

Midshipman G M Eady served in the Transmission Station of *New Zealand* at Jutland. The following passage is taken from the second, longer account 'written within a few months of the event' in a notebook donated to the Imperial War Museum by Commander G M Eady, RN.

> By 4.35 p.m.[71] the enemy's funnels were just visible on the horizon out of range but closing rapidly; the turrets were ordered to lay and train on the enemy and be ready for firing in every respect. Ranges now began to come through to us from the rangefinders in the turrets and foretop. The action, in so far as I and my assistant snotty were concerned, had begun. Facing us were six range transmitters worked by the men at each rangefinder.[72] As these flicked round altering the ranges it was our job to mark them down on a large moving roll of paper spread out on a table in front of us. This was called the Plotting Table. Two snotties and two A.B's as voice-pipe men completed the "Plotting Table's Crew". By plotting the ranges we were able to determine at what rate the enemy were opening or closing on us. The rates so obtained were passed to the gunnery lieutenant in the fore-top.[73]

[70] *Handbook 1918*, p.3.
[71] *New Zealand's* times were recorded in British Summer Time.
[72] This must refer to the six range receivers in the TS showing the ranges transmitted from the rangefinders.
[73] Midshipman G M Eady, 'Life in the Battle Cruiser Fleet 1916. Including an account of the Battle of

This account refers to a 'Plotting Table' rather than a 'Dreyer Table' and it makes no mention of the other principal components of the Mark I Dreyer Table, the Dumaresq and the clock, nor of their operators. The 'large moving roll of paper' could be part of the Dreyer range plot, but it could also be a description of the time-and-range roller boards issued in 1908, especially if these had been modified so that a hand drive, regulated with a stop-watch, advanced the paper at a steady speed. Thus it seems more likely that *New Zealand* had a manual range plotter rather than a Dreyer Table Mark I.

Bellerophon, Erin

On 24 September 1916, Admiral Jellicoe issued a memorandum requiring that:

> All battleships, battle-cruisers, cruisers and light-cruisers, engaged in the action of 31 May 1916, are to forward to the Admiralty their Dreyer table plotting charts and any other range and bearing records they may have...[74]

Of the surviving reports in ADM 116/1487, only those from *Bellerophon* and *Erin* give any indications of their fire control equipment.

> "BELLEROPHON"
> 10th October 1916.
>
> ....
> Sir,
>
> With reference to H. F. Memorandum...of 24th September, 1916 ordering Dreyer Table plotting charts of the action of 31st May 1916 to be sent to the Admiralty, I have the honour to report that very few ranges were obtained and though a small plot was made, it was of such little value that the record was not kept.
>
> I have &c.
> (Signed) Hugh Watson
> CAPTAIN.

> From The Commanding Officer, H.M.S. "Erin",
> ....
> 3rd October 1916...
> Subject: Rangefinding Plot of Action, 31st May 1916.
> ....
> ...only six ranges were taken altogether, at considerable intervals and no value could be obtained from them.
>
> The roll containing this information was therefore not kept and has since been destroyed.
>
> (Signed) V. A. Stanley,
> Captain.

Jutland, May 31st, 1916', original manuscript (used here) and 1964 typed transcript with corrections, 86/58/1, IWM.

[74] Admiral Jellicoe, Memorandum, 24 September 1916 in BTY 6/6, NMM.

The wording of *Bellerophon's* letter leaves little doubt that she had a Dreyer table. In contrast, the absence of any mention of a Dreyer table or Dreyer plot by *Erin* suggests (though by no means conclusively) that her plotter was probably still a simple time-and-range board.

Indomitable

After Jutland, the Grand Fleet developed the new system of ranging called ladder firing, in which the salvoes of brackets were fired in pairs. On 30 July, *Indomitable* reported:

> Rapid and early hitting A "Ladder" system of ranging has been introduced and thoroughly exercised both at the Spotting Table and at Control drill. The system appears to work well. A special pointer has been designed and made on board to enable the ranges to easily read off the Range Clock when using the "Ladder".[75]

In the Dreyer Table Mark I, the scale of the Vickers clock was replaced by a follower-ring, while the gun-range was read off the counter connected to the spotting differential. Thus this description is much more applicable to a ship using a standard Vickers clock, from which the ranges were called to the operators of the cross-connected range transmitters; it provides a clear indication that, in July 1916, *Indomitable* did not have a Dreyer Table.

Invincible

The following evidence was given before the Post War Questions Committee by Commander Hubert Dannreuther, who had been *Invincible's* gunnery officer at Jutland, stationed in the fore-top.

> Q. What instruments were used by you?
> A. I telephoned direct to each turret direct personal communications with officers in command of turrets. Otherwise, orders, which were very few, went through T.S.
> Q. T.S. is not necessary to you?
> A. I do not mean to imply that we used it to pass on ranges. The clock was down below.
> Q. And range [i.e. spotting] orders?
> A. Passed them usually from top of [to?] T.S. by voice pipe.[76]

Once again, this is not conclusive but the reference only to a clock in the TS again suggests that the Dreyer Table Mark I had not yet been fitted.

[75] Captain M H Hodges, *Indomitable* to RAC 2nd Batttle Cruiser Squadron, 30 July 1916 in 'Battle Cruiser War Records, Vol.VI, Miscellaneous', f.408, ADM 137/2134.
[76] Dannreuther before Post War Questions Committee in ADM 116/2060.

APPENDIX XIX

THE 'CRAB' LETTER

> ...In September 1907, Dreyer met Pollen while the inventor was on his way to Portsmouth to choose a position for his instruments on the protected cruiser *Ariadne*, which had been assigned to him as a trials ship, and Pollen later recalled that Dreyer "told me he hoped it would be his duty to crab me when the time came."
> The selection of Admiral of the Fleet Sir Arthur Knyvet Wilson to umpire the official trials insured that Dreyer's desire to play a major role in the blocking of Pollen would be fulfilled.[1]

At the hearing before the RCAI on 1 August 1925, Pollen recalled:

> ...It was quite a chance meeting; it was not arranged. Commander Fawcett Ray [*sic*][2] was the other. We three went down together....He [Dreyer] told me he hoped it would be his duty to crab me when the time came. I said I did not think he would. I should be the last person in the world to wish the Admiralty to adopt a stumour [*sic*][3] thing; I wanted them to have the best. [4]

Pollen did not have to rely on memory for this encounter, since he had referred to it in a friendly letter written to Dreyer on 4 January 1908 to congratulate him on his promotion to Commander. Typed copies can be found in the Claims Files for the RCAI hearings and in the Dreyer Papers.

COPY

188 Fleet Street
London E. C.
January 4th, 1908.

Dear Dreyer,

Please forgive me for dictating this, but I am in a rush to get things done before going down to Portsmouth to join the Ariadne.

[1] Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) pp.121-4.
[2] Fawcet Wray had invented an early form of range clock: Chapter 3.
[3] The *Shorter Oxford Dictionary* (3rd edition) does not contain this word but defines:
Stumer...*slang*. 1890...A worthless cheque; a counterfeit note or coin...also a dud.
[4] RCAI Minutes of Proceedings, T.173/547 Part 14, p.84, PRO

I need not tell you how gratified I am by the announcement in the promotion list. Some junior promotions cause heart burning. Yours is one which I think everyone - senior and junior - will think is as right as it could be, and absolutely to the good of the Service.

We have had two talks in the last six months - one when we parted at the Midland Station after your visit to Manchester, when you assured me of your heartiest good wishes for the success of the A.C apparatus.[5] On the occasion of our last meeting, going down to Portsmouth, you warned me that you hoped it would be your duty to crab it if you could. I know that in both wishes you were absolutely sincere. I was as grateful as possible for the first, and I welcome as heartily as I can the second.

Personally, I am strongly convinced that, unless the system is crab proof, and crab proof from the strongest quarter from which crabbing can come, the Service ought not to go to any exceptional expense or trouble to acquire it; but I am also confident that, when you get to the bottom of it, you will find that it is crab proof.

No doubt we shall have an opportunity in the course of the trials for going into all the different details. It certainly was a stroke of genius on Captain Bacon's part appointing Wilson to superintend the thing and to report on it. You of course have known him well for years. To me he is an absolute revelation in this sense - that I have never before met in any walk of life the combination of practical judgement and theoretical appreciation that he seems to embody. It is impossible to believe that the age limits are rightly imposed in instances like this, and, considering how critical the state of the Navy is today, in the sense that we seem to be working through epochs of technical development with such appalling rapidity, it looks as if it were a real misfortune that his commanding influence over naval work should be removed. Needless to say, I take it as far the greatest compliment that has been paid to my invention so far that he should have accepted the job of reporting on it, and my admiration for the D.N.O. in having persuaded him to do so is unbounded, and my gratitude likewise.

So, all good wishes and most sincere congratulations.

I am,

Yours sincerely,

(sd.) A.H.Pollen

Commander F.C.Dreyer
The Admiralty,
Whitehall.[6]

The *Shorter Oxford Dictionary* gives two relevant definitions of 'to crab':

Crab...To go counter to, to cross....[Scots, latest recorded use] 1605....To criticize adversely...pull to pieces (*colloq.*) 1812.

Thus Dreyer's declared intent to 'crab it' (the apparatus) rather than to 'crab me' (Pollen), and Pollen's acceptance that this was his proper role, establishes that Dreyer was using the verb in its more recent colloquial sense rather than in the archaic Scots usage.

[5] Dreyer was in the delegation which visited the Linotype works at Broadheath, Manchester on 11 June 1907. *IDNS*, pp.121 and 123. Pollen before RCAI, T.173/547 Part 14, p.82.

[6] Pollen to Dreyer, 4 January 1908 in DRYR 2/1, CC and RCAI Claims Files, T.173/91 Part III.

APPENDIX XX

DREYER AND THE 13.5-INCH GUN

When Bacon took over as DNO, Dreyer's responsibilities included non-transferable (turret) mountings (except electrical).[1] In his memoirs, Dreyer stated:

> In 1908 we were getting excessive spreads in range and accuracy trials from the 50 calibre 12-inch guns...intended for...the *St. Vincent* class....At this time I came across an article...in connection with U.S. coast-defence guns, giving the arguments in favour of mounting low-muzzle-velocity 14-inch guns instead of high velocity 12-inch ones. I discussed this with Commander H. G. R. Bevan, R.N., who specialised in gun design for the Chief Inspector of Naval Ordnance, and we agreed that this was a good proposition....I took the matter to the D.N.O., who asked Commander Trevor Dawson of Vickers what he could do. The latter soon returned with the design of a 13.5-inch gun [and] the outline design of a twin 13.5-inch turret....The D.N.O., after consulting the Director of Naval Construction, myself...Commander...Bevan, and Engineer-Admiral E. F. Ellis about the turret, then put forward the proposal to Jellicoe, who had returned to the Admiralty as Third Sea Lord and Controller, for the adoption of 13.5-inch guns for the projected *Orion* class of battleships and the *Lion* class of battle-cruisers. This was given Board approval and was a great advance.[2]

This passage gives a valuable insight into the workings of the DNO's department, both internally and with other Admiralty departments and industry. However, it also leaves the impression that Dreyer was a principal instigator of the increase in calibre for British capital ships. In fact, the idea had been considered as far back as the summer of 1906 for the 1907-08 programme; for a short time, the alternatives were discussed of either eight 13.5-inch guns (in dual turrets) or twelve 12-inch, 50 cal. guns in triple turrets.[3] In January 1908 Fisher, inspired by Bacon, was pressing for the adoption of the heavier piece and, as Sumida suggests, Dreyer may have contributed to a paper on its merits, which was

[1] *Paper prepared by Director of Naval Ordnance for the Information of his Successor*, July 1907, p.49, AL.

[2] Frederic Dreyer, *The Sea Heritage* (London, 1955) pp. 59-60.

[3] Minutes by DNO (20 June) and DNC (10 August 1906) in Ship's Cover 223 (untitled), ADM 138/251, NMM. On 20 August, a conference in the First Sea Lord's room recommended 12-inch, 50-cal. guns with turrets in the Dreadnought layout but with 3 guns in X turret. See further John Brooks, 'All-Big-Guns: Fire Control and Capital Ship Design 1903-1909' in *War Studies Journal*, Spring 1996, Vol. 1, Issue 2, pp.45-6.

printed in April 1908 (though this makes no mention of American guns).[4] Jellicoe returned to the Admiralty as Controller in October 1908 but the decision to proceed with even the first trial gun was not taken until the end of the year.[5] Board approval, in principle, for the new 13.5-inch battleships and battlecruisers was given by the end of May 1909.[6]

Dreyer's involvement with these events remains unclear. In his outgoing report, Bacon noted that:

> The procedure as regards gun mountings has been improved, and now conferences are held regularly at the Admiralty to discuss and pass drawings...delay in design is almost completely obviated.

However, there had also been changes to the responsibilities of the DNO's assistants and Lieutenant Henley (who had replaced Dreyer) was no longer responsible for hydraulic mountings.[7] In view of his considerable workload (and the many innovations with which he had been involved), it seems probable that, at some time after October 1908, Dreyer had been relieved of his duties respecting gun mountings and so was probably not involved in the detailed designs for the 13.5-inch mountings.

[4] Jon Sumida, *In Defence of Naval Supremacy* (London, 1989) p.161. Copies of the memorandum are in DRYR 2/1 and FISR 8/29, FP 4872, CC.

[5] 'New Design 13.5 inch B.L. Guns. Tender for supply of one to V.S.M. design', ADM 1/8064. The First Lord gave approval to proceed on 21 December 1908.

[6] Admiralty Board Minutes, 12 and 27 May 1909 in ADM 167/43.

[7] *DNO for Successor (op. cit.)* November 1909, pp. 2 and 41.

APPENDIX XXI

HENLEY TO DREYER, 13 AUGUST 1910

Henley's letter exists as a typed transcript in the Dreyer Papers. Its informal style suggests that it may originally have been hand-written. The transcript was probably made for the hearings before the Royal Commission for Awards to Inventors.

13th August 1910.

My dear Dreyer

x x x x

Re Plotting.

Your screed on T.&R. & T.&B.[1] has come in officially and gone on but everyone so far is opposed to making it automatic.

Since I last wrote Mr. Pollen appeared one day and informed me he was preparing a scheme for Automatic Time and Ranges Plotting. I said nothing about you having already got the Secret patent for a Time and Range Board but I am pushing on the papers submitting that you should take out a Secret Patent for the whole system of T.&R. & T.&B. plotting whether done manually or automatically and also asking you for drawings of Auto T.&R. and Auto T.&B. board.

Mr. P. may have been on this T.&R. scheme for some time but so far we have no information of any patent having been lodged. (Personally I expect he has heard of your scheme through somebody and this has given him the idea).

There seems no reason why we should not have the patent for the principle of auto T.&R. even if we have to fall back on Mr. P's Auto Receiver to do it.

....

Re Pollen R.F. by terms of contract we shall not get the first one until September 1911 so am afraid it will be towards the end of your commission.

[1] This must be 'Remarks by Commander F.C. Dreyer on the question of how best to obtain and maintain the gun range in action', 22 July 1910 in RCAI Claims Files, T.173/91 Part III (also in ADM 1/8147).

In view of Mr. P's sudden attack on T.&R. I concur with you re secret patents and I hope you agree with me that the patent should cover the whole principle of T.&R. & T.&B. so as to keep him out of it.

I read your letter to Capt. Craig re "your attack on Mr. P." and I certainly did not read your screed in any way as an uncalled for attack or [sic] that gentleman entre nous.[2] We have it in writing now that he foregoes all claims to the principle of plotting so we are now square with him on that point.[3]

....

I hope the Sec^y [Secondary] control may be successful as a good deal in the way of future supply depends on it.

Best wishes for a magnificent B.P. [Battle Practice]

Yours ever,

J.C.W. Henley[4]

[2] Captain Arthur Craig was Assistant DNO. In his 'Remarks' of 22 July, Dreyer had again asserted that Pollen's machinery was 'on the system invented by the late Colonel Watkins [*sic*] R.A. (and employed for the last twenty years or more years in nearly all our shore forts'. Perhaps Captain Craig took exception to this: or alternatively Dreyer had been more forthright in another 'screed' which has not come to light.

[3] In the contract for the production order for rangefinder mountings, Argo were required to acknowledge that the agreement of 18 February 1908 was a 'dead letter' and that the Admiralty-pattern plotter did not infringe their patents: Secretary of the Admiralty to Argo Co. with enclosures, 29 April 1910 in T.173/91 Part VII, PRO.

[4] Henley to Dreyer, 13 August 1910 in DRYR 2/1, CC.

APPENDIX XXII

ERRORS FROM STEPWISE CHANGE OF RATE

1. Let f(t) be some function of time t, and let its first, second,...nth derivatives be represented by $f', f'', ...f^{(n)}$.

2. Consider an interval of time before and after a time $t = a$ such that:

$$a - \tau < t < a + \tau$$

Assume that, in this interval, the derivatives of f(t) are all finite. Let:

$$|h| < \tau \qquad \text{and} \qquad 0 < \theta_n < 1$$

Then if: $R_n = \frac{h^n}{n!} f^{(n)}(a + \theta_n h)$ tends to zero as n tends to infinity

$f(a + h)$ can be expressed in Taylor's series[1] as:

$$f(a+h) = f(a) + hf'(a) + \frac{h^2}{2!}f''(a) + \frac{h^3}{3!}f'''(a) + \frac{h^4}{4!}f''''(a) + \ldots \qquad \text{(XXII:1)}$$

3. Similarly, for the function $f'(t)$ which is the differential of f(t) with respect to time:

$$f'(a+h) - f'(a) = hf''(a) + \frac{h^2}{2!}f'''(a) + \frac{h^3}{3!}f''''(a) + \ldots \qquad \text{(XXII:2)}$$

4. Let g(t) be the function of time generated by an integrator set for rate at intervals. Let the integrator be set with rate $f'(a)$ at time a and let the integrator run at that rate for the time interval h. Then:

$$g(a+h) = g(a) + hf'(a)$$

5. Let $\varepsilon = g - f$ be the difference or error in g with respect to f. Let ε increase by $\delta\varepsilon$ in the interval h. Then:

$$\delta\varepsilon = g(a+h) - f(a+h) - g(a) + f(a)$$
$$= -f(a+h) + f(a) + hf'(a)$$

and substituting from XXII:1:

$$\delta\varepsilon = -\frac{h}{2}\left(hf''(a) + \frac{2}{3}\frac{h^2}{2!}f'''(a) + \frac{2}{4}\frac{h^3}{3!}f''''(a) + \ldots\right) \qquad \text{(XXII:3)}$$

[1] C J Tranter, *Techniques of Mathematical Analysis* (London, 1957) p.225.

6. Assume that the rate of the integrator is changed in steps of constant size ρ i.e.

$$f'(a+h) - f'(a) = \rho$$

so, from XXII:2:

$$\rho = hf''(a) + \frac{h^2}{2!}f'''(a) + \frac{h^3}{3!}f''''(a) + \dots \qquad \text{(XXII:4)}$$

7. The series in XXII:3 and XXII:4 are converging. Make the further assumption that they converge rapidly such that:

$$f''(a) >> \frac{h}{2!}f'''(a) + \frac{h^2}{3!}f''''(a) + \dots \qquad \text{(XXII:5)}$$

Then: $\rho \simeq hf''(a)$ (XXII:6)

and $\delta\varepsilon \simeq -\dfrac{h\rho}{2}$

Since this indicates the change in error in a time h, the rate of change of error is:

$$\frac{d\varepsilon}{dt} \simeq -\frac{\rho}{2}$$

8. This is the same result obtained in Appendix VIII specifically for the hyperbolic range-time function. Does this function satisfy the inequality XXII:5? This can be investigated using the rate equations from Appendix I for steady courses:

$$R' = a \qquad\qquad x' = -\frac{ax}{R}$$

$$R'' = a' = \frac{x^2}{R}$$

Therefore: $R''' = \dfrac{R.2x.x' - x^2.R'}{R^2} = -\dfrac{3ax^2}{R^2}$

and
$$R'''' = -3\left(\frac{R^2(a.2x.x' + x^2.a') - ax^2.2R.R'}{R^4}\right)$$

$$= -3\left(\frac{R(-2ax.ax + x^4) - 2R.ax^2.a}{R^4}\right)$$

$$= \frac{12a^2x^2 - 3x^4}{R^3}$$

9. From XXII:6:

$$h \simeq \frac{\rho}{R''}$$

Consider initially the first term of the series on the right-hand side of XXII:5; it is necessary to verify that:

$$R'' >> \frac{h}{2}R'''$$

or, after substituting for h, that:

$$\frac{\rho R'''}{2R''^2} << 1$$

$$\frac{\rho R'''}{2R''^2} = -\frac{\rho}{2}\cdot\frac{3ax^2}{R^2}\cdot\frac{R^2}{x^4} = -\frac{3\rho a}{2x^2}$$

Rates have to be transferred to the range-clock in steps when the rate is changing rapidly. This condition arises when the range is fairly near the minimum of the range-time hyperbola. Assume that the angle γ (introduced in XVIII-11) is less than 45°; then

$$a < \frac{v}{\sqrt{2}} \qquad \text{and} \qquad x > \frac{v}{\sqrt{2}}$$

Thus $$\frac{3\rho a}{2x^2} < \frac{3\rho}{\sqrt{2}\,v}$$

If rate steps are of 25 yds/min. and the speed-across and virtual speed are a high 50 knots:

$$\frac{3\rho}{\sqrt{2}\,v} = \frac{3\times 25}{\sqrt{2}\times 50\times 33.78} = 0.031$$

Thus, for the first term of the series, the condition for rapid convergence (XXII:5) is met. If the virtual speed is lower, the range-time hyperbola is less sharply curved but the ratio can be held below 0.1 by reducing the maximum value of γ i.e. using rate transfer in fixed steps only when the curvature is near its maximum.

10. To verify that convergence is rapid, the same values can be used to evaluate the second term of the series:

$$\frac{h^2R'''}{3!\,R''} = \frac{\rho^2R'''}{6R''^3} = \frac{\rho^2R^3}{6x^6}\cdot\frac{12a^2x^2-3x^4}{R^3}$$

$$= \frac{\rho^2}{x^4}\left(2a^2 - \frac{x^2}{2}\right) > -\frac{\rho^2}{2x^2}$$

$$\frac{\rho^2}{2x^2} = \frac{25^2}{2(50\times 33.78)^2} = 0.0001$$

Thus, the series does converge rapidly.

11. When own ship is altering course, the equations for R and R' remain unchanged but, from III:5:

$$R'' = \frac{x^2}{R} - s\,\sin\beta.\dot{\kappa} \qquad \text{(XXII:7)}$$

$$R''' = -\frac{3ax^2}{R^2} - s.\dot{\kappa}.\cos\beta.\frac{d\beta}{dt}$$

and, from III:2 and III:3:

$$R''' = -\frac{3ax^2}{R^2} - s.\dot{\kappa}.\cos\beta.\frac{x}{R} + s.\dot{\kappa}^2\cos\beta \qquad \text{(XXII:8)}$$

Again, it is necessary to determine whether:

$$\frac{\rho R'''}{2R''^2} << 1$$

First consider the conditions in which $x \to 0$ i.e. curvature of the range-time graph is due only to change of course. Then:

$$\frac{\rho R'''}{2R''^2} \simeq \frac{\rho\, s\, \dot{\kappa}^2 \cos\beta}{2\, s^2\, \dot{\kappa}^2 \sin^2\beta} = \frac{\rho \cos\beta}{2\, s \sin^2\beta}$$

$\rho = 25$ yds/min. and assume $s = 25 \times 33.78$ yds/min. Hence:

$$\frac{\rho}{2s} = 0.015$$

and the approximation holds, unless $\beta \to 0$. However, if own ship is headed along the line of target bearing and $x \to 0$, the enemy course must also coincide with the line of bearing. Thus the speed-along must be nearly constant i.e. the range-time graph must be straight, so there is no need for the transfer of range-rate in steps.

Now look for a condition which maximises R''' and minimises R''. With the target before the beam, the third term for R''' (XXII:8) is positive and a maximum when $\beta = 0$. The second term is also maximised by $\beta = 0$ and can be positive if x and $\dot{\kappa}$ have opposite signs. The first term will be positive if a is negative and will be large if both a and x are significant. All these conditions are met if an enemy is crossing own ship's 'T': when the second term of R'' (XXII:7) is zero. Assume a range of 8,000 yards: that s and e, and hence a and x, are all 25 knots: and that $\dot{\kappa}$ is 20°/min. The different terms evaluate to:

$$\frac{3ax^2}{R^2} = \frac{3(33.78 \times 25)^3}{8000^2} \simeq 28$$

$$s\dot{\kappa}\left(\frac{x}{R} + \dot{\kappa}\right) = 25 \times 33.78 \times 20 \times \frac{\pi}{180}\left(\frac{25 \times 33.78}{8000} + 20 \times \frac{\pi}{180}\right)$$

$$\simeq 134$$

$$\frac{x^2}{R} = \frac{(33.78 \times 25)^2}{8000} \simeq 89$$

Thus: $$\frac{\rho R'''}{2R''^2} \simeq \frac{25 \times 162}{2 \times 89^2} = 0.26$$

Hence, for this worst case condition, the expression is less than, but not much less than, one. The approximation for error-rate is, therefore, not always exact; however, it still gives a good order-of-magnitude indication of the errors resulting from stepwise rate transfer when the rate itself is changing.

APPENDIX XXIII

THE LATER DREYER TABLES

MARK I*

The Mark I* was derived directly from the Mark I and still relied on a Vickers clock; the major difference was the addition of gyro compass control gear coupled to the Mark VI* Dumaresq. In 1918, two of these tables had been allocated to the coast defence vessels *Glatton* and *Gorgon* (completed between 1915 and mid-1918), while a further five were destined for the *Hawkins* class.[1] These cruisers were ordered in December 1915 but not completed until after the War; by 1930, *Hawkins* (the first of the class completed) had (or was about to have) a Mark IV* table, while the other two surviving members had already received the more elaborate Mark III* table.[2] Thus it appears that the Mark I* had only a short service life before it was superseded or upgraded to Mark III*.

MARK III*

The 1918 *Handbook* shows that, as originally designed, the Mark III* was a further development of the Mark I*: though it was capable of plotting up to 29,000 yards (at 600 yards per inch) without shifting the range scale. It also used a Mark VI* Dumaresq coupled to a gyro compass receiver; however, the Vickers clock was replaced by a range clock 'similar to that in the turret instrument'. A further novelty was the introduction of a multiplying linkage which, when set with Dumaresq Deflection and range, automatically computed the component of gun deflection due to speed across; this was then applied to the deflection totaliser. However, both range and Dumaresq deflection had to be set on

[1] *Handbook of Captain F.C. Dreyer's Fire Control System, 1918*, C. B. 1456, p.3, AL. *Jane's Fighting Ships of World War I* (London, 1990) p.63.

[2] 'Pamphlet on the Mark III* Dreyer Table, 1930' and 'Pamphlet on the Mark IV* Dreyer Table, 1930' in 'Guard Book for Pamphlets on Dreyer Tables', AL. *Jane's* (*op. cit.*) p.56: J J Colledge, *Ships of the Royal Navy* (London, 1987).

the linkage by hand, the latter being read off the Dumaresq dial itself. As for all other tables, the 1918 *Handbook* shows the Mark III* table with the cancelled new-pattern bearing plot.[3] This was subsequently replaced by GDT gear: which required that the table be provided with a bearing clock.[4] However, the bearing rate was set by hand with the aid of a graduated drum, just like that used in the Mark III table. Thus the approximations inherent in manual setting were accepted for the ships in which the Mark III* was installed. By 1930, these were the cruisers *Frobisher* and *Effingham* (*Hawkins* class), *Emerald* and *Enterprise*, eight *D-class* ships and five *Carlisle* class. The aircraft carriers *Eagle* and *Hermes* also had Mark III* tables, though without GDT gear.[5]

MARK V

The ultimate development of the Dreyer Table was the Mark V. The 1918 *Handbook* applied this mark number to the tables for both *Ramillies* and *Hood* and described an improved version of the Mark IV*. Like the Mark III*, this table also had a linkage for generating the component of gun deflection due to speed across. However, both Dumaresq deflection and gun range were set automatically: while an operator only had to follow a pointer to transfer the deflection from the linkage to the deflection totaliser. This linkage was first supplied as part of the table for *Ramillies*, which was otherwise much like the preceding Mark IV*s.[6] However, after the publication of the 1918 *Handbook*, the design of the table for *Hood* continued and radical alterations were introduced in line with the recommendation of the Grand Fleet Dreyer Table Committee (see Chapter 6). In addition to the inclusion of GDT gear, the deflection gear was further elaborated, on the principles developed by Commander Graham-Brown, so that deflection could be automatically adjusted for changes in wind-across induced by course alterations.[7] The range plot and its associated transmitters and receivers were completely redesigned, much of the additional equipment arising from fittings required for concentration firing. The plot was now fitted with five screws; to give a clearer view, they were all moved to the back of the table. Clock range and gun range screws functioned as in previous marks. A

[3] *Handbook 1918* (*op. cit.*) pp. 19 and 42, Plates 7 and 20.
[4] Admiralty, Gunnery Branch, *Progress in Gunnery Material 1921*, p.9 and Fig.1, ADM 186/251.
[5] 'Pamphlet Mark III*, 1930' (*op. cit.*) p.1. and Plate 2.
[6] *Handbook 1918*, pp.23 and 44, Plates 11 and 20
[7] DNO's minute 24 February 1919 in 'Monthly Record of Principal Questions dealt with by director of Naval Ordnance', Vol.III, January to June 1919, p.1110, AL. Papers of Commander David T Brown, *Excellent* Historical Library.

typewriter for own rangefinder ranges was now positioned by a third screw and its electro-pneumatic typing head was controlled remotely; later, screw positioning was found to be too slow and replaced by a wire loop. A fourth screw with typewriter was used to plot incoming ranges from one or two consorts, corrected for position-in-line (P.I.L.). Finally, a consort's range pencil, its screw driven by the clock, could be independently tuned to the mean of the consort ranges (just as the clock range was tuned to own ship's ranges). To further improve the view of the plot, the circular wire grid was replaced by a projector mounted above the table, which cast an image of parallel lines onto the plot. As with the Mark III*, ranges up to 29,000 yards could be plotted (at a scale of 600 yards per inch) without changing scales.

The many additional loads on the range plot evidently proved too much for the variable speed drive.

> These are the same as fitted to the Mark IV* tables, but in order to increase the power of the clocks the speed of the friction discs have been doubled...this speed being reduced in the case of range in the tuning differential box, and in the case of bearing in the sprockets...driving the inner ring of the Dumaresq.[8]

Initially this seems to have been sufficient. In 1921, the table was described as 'a great improvement on all previous Marks of Dreyer Table.' In 1922, Hood opened on the ex-German cruiser *Nurnberg* (towed by *Repulse*) at 28,000 yards and: 'Excellent results were obtained at ranges between 26,500 and 23,000 yards'. In 1923, against the radio-controlled target ship *Agamemnon*, 'H.M.S. Hood obtained an extraordinarily high percentage of hits e.g. 40 hits out of 100 rounds fired'.[9]

Despite these satisfactory results, subsequent developments suggest that (as would be expected) slip-induced errors in the range clocks had been reduced but not eliminated: and complaints continued to be received about the overloading of existing Dreyer tables, though these were also refitted.[10] A complete solution depended on the development during the 1920s of improved servo followers, initially for the Admiralty Fire Control Table Mark I. A standard form of sensitive 'hunter' mechanism used differentials to detect any misalignment between a low-power input shaft and a motor-driven output; the hunter was then arranged to control either an air-motor or an electric clutch-brake motor.[11] The

[8] Admiralty, Gunnery Branch, *Progress in Gunnery Matériel 1920*, pp. 8-12 and Fig.1, ADM 186/244.
[9] *PGM 1921* (*op. cit.*) p.9. Admiralty, Naval Staff, Gunnery Division, *Progress in Naval Gunnery 1922*, pp.3 and 25 (ADM 186/258) and *Progress in Naval Gunnery 1923*, p.12 (ADM 186/261). *Agamemnon* zig-zagged but only at 8 knots.
[10] *PNG 1922* (*op. cit.*) p.27.
[11] Admiralty, Gunnery Branch, *Handbook for Admiralty Fire Control Table Mark I*, 1927, pp.6-10, 12-14 and

latter had been adopted for the Mark V table by 1930, so that all the fittings on the range plot were driven by this motor, which, through the action of the hunter, followed the range clock output shaft; thus the load on the clock was reduced to nothing more than the hunter itself.[12] The clutch-brake motor was designed to reduce greatly the overshoot and oscillation previously associated with contact-controlled motorised followers. Its operation depended on sensitive electric contacts in the hunter; if either contact closed, the motor drove the output shaft through an electrically-operated clutch in the direction necessary to realign the output and input shafts. As soon as they were once more aligned, the hunter contact opened. This not only removed the power to the motor; the clutch was also released and, instead, an electrically-operated brake on the output shaft was energised. Thus, at once, the inertia of the motor was disconnected from the output shaft, while a brake was applied to the shaft (and all its connected loads).

> The gear should be adjusted to operate in steps of about 10 yards. If the [hunter contact] gaps are made too small, a continuous oscillating motion will be set up in the power driven side of the mechanism which will cause unnecessary strain and burn out the contacts and relays. The contacts require to be cleaned regularly.[13]

Thus, with this new servo follower, the load on the range clock was negligible and, when the contacts were in proper adjustment, overshoot was negligible.[14]

MARK IV*

The table in *Hood* remained the only Mark V afloat.

> This table is based on a design which is now several years old and may be said to have reached finality.[15]

However, while the future lay with the new Admiralty Fire Control Tables, existing capital ships had to make do with Dreyer Tables, and by 1930, the standard table for all other 15-inch ships, the *Iron Duke* class and *Tiger* (as well as *Hawkins*) was the Mark IV*. Compared with the original version, the main changes were the replacement of the

Figs. 24-6, ADM 186/273-4.

[12] A clutch could disengage the clutch-brake motor and connect the range-clock directly to the plot and all its attachments. The retention of this option suggests that, if the power follow-up gear failed, the clock could still generate usable ranges, though perhaps with appreciable errors.

[13] 'Pamphlet on the Mark V Dreyer Table,1930', p.21 et seq. in 'Guard Book' (*op. cit.*)

[14] The hunter and clutch-brake motor still constituted a bang-bang servo system. Thus a slow movement could not be followed continuous but by a series of small, 10 yard steps. The development of followers which operated smoothly and accurately was one of the greatest technical challenges facing the designers of the AFCT Mark I and its successors.

[15] *PGM 1921*, p.9. Three other Mark V tables were supplied to *Excellent* and the Chatham and Devonport Gunnery Schools: 'Pamphlet Mark V 1930' (*op. cit.*) p.1.

bearing plot by GDT gear and the addition of a second gun range plot, on which concentration information could be plotted. Furthermore, the Mark IV* tables were also fitted with the power follow-up gear based on the clutch-brake motor.[16] Thus, like the Mark V, the Mark IV* benefited from the advances in servo-followers made during the development of the early Admiralty Fire Control Tables. Some of the most important features of these entirely new designs are described briefly in the Chapter 6. However, after *Nelson* and *Rodney* (AFCT Mark I), the next six marks were allocated to new cruisers. It was not until the complete reconstruction of *Warspite* that the AFCT Mark VII (a direct descendent of the AFCT Mark I) was designed to fit into the new (and presumably enlarged) transmitting station. The 1939 Addendum to the Handbook for the Mark VII handbook stated that: '[This] type of table is expected to be supplied to H.M.S. HOOD...and is also being provided for H.M. Ships QUEEN ELIZABETH, VALIANT, RENOWN and REPULSE with modifications to suit their new secondary armament of 4.5-inch guns'.[17] These intentions were carried out for the three ships then being reconstructed:[18] but the new war prevented any drastic alterations being made to *Hood*[19] and *Repulse* and there are no indications that their Dreyer Tables had been replaced before they were lost. Similarly, neither *Barham*, *Malaya* nor any of the '*R*' class were reconstructed and it appears that all these old ships fought in World War II with fire control tables dating back to the previous conflict.

[16] 'Pamphlet Mark IV* 1930', pp.6, 25-7 and Plate 2.
[17] Admiralty, Gunnery Branch, *Handbook for the Admiralty Fire Control Table Mark VII 1939*, Addendum No.1, p.7, ADM 186/357 (II).
[18] Ledger 1.05/2 in the Elliott Brothers Archive (19 October 1942 to 25 March 1944) records work on Admiralty Fire Control Tables in *Renown*, *Valiant* and *Queen Elizabeth*.
[19] Stephen Roskill, *Admiral of the Fleet Earl Beatty* (New York, 1981) p.66.

Appendices to Chapter 6

APPENDIX XXIV

GERMAN FIRE CONTROL

DEVELOPMENT

In some aspects of fire control, the Germans were ahead of the Royal Navy in the early years of the century. They had been first to adopt fire control instruments[1] and it will be recalled that many British pre-dreadnoughts had been equipped by Siemens and Halske; for German ships, the firm supplied range, deflection, bearing and order instruments.[2] In contrast, Zeiss did not introduce a stereoscopic naval rangefinder until 1906, their first model being relatively short at 1.44 m (4.72 feet). However, their 3 m instrument was accepted by the German Navy as soon as it was introduced in 1909 (though large orders may not have been placed until 1912).[3] Two versions were in service during the War. The tube of the turret model was under the roof, with prismatic objectives protruding through it. On the control towers, the main tube of the rangefinder rotated above the roof, while extension tubes brought the images down to the rangetaker in the tower. Because of the errors arising only in the prismatic ends, the turret rangefinders may have needed continual adjustment[4] and most reliance seems to have been placed on the control tower rangefinder;

> ...in the *Ostfriesland*, it was the practice to station a very skilful observer [at] the rangefinder in the fore control tower, and to use the ranges taken by him for purposes

[1] Captain Edward Harding, 'Memorandum on the Professional and Financial Value of the A.C. System' with letter of 4 September 1906 in T.173/91 Part VII, PRO.

[2] Naval Staff, Intelligence Department, *Report on Interned German Vessels. Gunnery Information*, February 1919, pp.8 and 18, ADM 186/240. Guy Hartcup, *The War of Invention* (London, 1989) pp.12 and 14.

[3] Karl Lautenschläger, 'The Dreadnought Revolution Reconsidered' in Daniel Masterson (ed.) *Naval History, The Sixth Symposium of the U.S. Naval Academy* (Wilmington, Delaware, 1987) p.125. Michael Moss and Iain Russell, *Range and Vision - the First Hundred Years of Barr & Stroud* (Edinburgh, 1988) pp.65 and 68.

[4] *Interned German Vessels*, 1919 (*op. cit.*) pp.8,17 and 34-5. Naval Staff, Intelligence Division, *Reports on Interned German Vessels, Part V Gunnery Material*, October 1920, (C.B. 1516E), p.8, ADM186/243.

> of control, exercising a check over his ranges by an occasional mean taken from the Mittlungs Apparat [*q.v.*].[5]

Longer instruments were not introduced until 8.2-metre rangefinders were installed in the turrets of *Bayern* and *Baden*.[6] The Royal Navy also believed that the *König* class had 5 and 8m rangefinders and that other ships may have carried instruments larger than 3-metre:[7] but these assumptions were not born out by post-War investigations.

By 1908, the Germans had developed their own version of the Dumaresq, called the EU-Anzeiger (Plate 52), though the disc of the instrument was only calibrated with lines of constant range-rate.[8] The Royal Navy learned from intelligence sources that:

> ...in July 1910...the German Fleet had carried out their exercises with heavy guns at ranges up to 10,000 yards and that the system of obtaining 25 per cent of short shots had been adopted.[9]

However, these firings may have been without the aid of range clocks, since, by 1918, British intelligence had concluded that clocks had not been introduced until about 1912. An older model had a spiral range scale on a revolving drum; a later design had both a circular range scale and a digital indicator which clicked round in steps of 50 metres, as well as a digital indicator of the rate.[10] German reports on the Firing Practices for 1913-14 stated that: 'The ranging was carried out by all ships with the range clock', though the wording suggests this was still something of a novelty.[11] Initially, the clock ranges were probably transmitted to the guns using the existing Siemens instruments (which were retained until the end of the War)[12] and transferred manually to the sights. However, in 1912, trials were held in *Blücher* of an Elevation Telegraph, which worked with elevation receivers in the turrets; the system was adopted as the Aw-Geber C.12.[13] The elevation telegraph incorporated the range-clock, almost certainly the later model. Although

[5] *Seydlitz*, 'General Experience' in *Jutland, Later Reports*, f.272, ADM137/1644. Naval Staff, Intelligence Department, *German Gunnery Information Derived from the Interrogation of Prisoners of War*, October 1918 (C.B.01481), p.18, Ca 0108, AL.

[6] *German Gunnery Material*, 1920 (*op. cit.*) p.7-8.

[7] Royal Navy, *German Warships of World War I* (London, 1992) pp.4, 7, 10 and 24: this reproduces Confidential Books dating from 1918.

[8] Peter Padfield, *Guns at Sea* (London, 1974) p.228. The instrument was described and illustrated in *Information from PoWs*, 1918 (*op. cit.*) p.16-17 and Plate 3. EU (Entfernungs Unterschieds) Anzeiger means range difference indicator and is the term used by Padfield and von Hase (q.v.). The intelligence report calls the instrument an E U Pielscheiber (range difference bearing disc).

[9] Admiralty, *German Navy, Part IV Section 4, Target Practice, Rangefinders and Control of Fire*, July 1917 (C.B. 1182A) p.5, Ca 0106, AL.

[10] *Information from PoWs*, 1918, p.16 and Plate 3.

[11] *German Control of Fire*, 1917 (*op. cit.*) p.10.

[12] *Interned German Vessels*, 1919, pp.7-8 and 18.

[13] Lautenschläger, 'Dreadnought Revolution' (*op. cit.*) p.135.

Derfflinger's gunnery officer at Jutland, Commander Georg von Hase, does not give full details, it is clear that the clock generated the gun-range and that the elevation telegraph converted range into elevation before transmitting elevation to the guns. In the turrets, the sights were set for elevation by following a pointer. Thus the system was identical in principle to that in British ships with Dreyer Tables; the connection between the range-clock and the elevation-transmitter may have been automatic or, like the British scheme, it may have depended on an operator following another pointer.

Unlike their opponents, the German ships at Jutland did not have full range-and-bearing directors; instead their directors transmitted only target bearings. However, because the main observation instrument was located in the armoured control positions, and was used by the control officer, it also acted as the target designator.[14] Development of this training director may have begun as early as 1908 but initial trials, in *Blücher*, were not held until 1914, while all the true battlecruisers (except *Goeben*) were fitted during 1915. One model was designated Rw-Geber C.13,[15] while *Derfflinger* at Jutland had the then new C/XVII. The master instrument was periscopic, the objectives protruding through the roof of the armoured control tower in rear of the conning tower; the control officer viewed his target through binocular eyepieces while a separate trainer used a monocular eyepiece at the side. *Seydlitz*, which had an older model than *Derfflinger*, found:

> ...the eye-piece at the side...was useless nearly the whole time, so that the Gun Control Officer had to serve the Director Gear himself.[16]

Derfflinger's main director was also supplemented by a periscope in the fore-top; its bearing was transmitted to the main instrument, on which the trainer could follow the aloft pointer if he could not see the target himself. The complete installation was a true training director, compensating for the distances between the turrets in setting the bearing indicators in each. Thus the turret trainers only needed to follow the pointers to keep their guns - and the turret rangefinders - on the target.[17]

[14] Georg von Hase, *Kiel and Jutland* (London, 1921) pp.79-83. In the British system, the Evershed indicated the target for director, rangefinders and turrets.

[15] For installation dates see Lautenschläger, 'Dreadnought Revolution, p.135 and John Campbell, *Warship Special 1. Battlecruisers* (London, 1978) pp.19, 22, 43 and 49; *Lützow* was completed with a director and *Goeben* fitted in later 1916 or 1917. Padfield, *Guns at Sea* (*op. cit.*) p.252 states that the Germans had a partial director system under experiment from 1908; he illustrates the wartime apparatus on p.271. German terms for the training director were Zielgerät (target-gear) - see Lautenschläger - and Richtungsweiser Sehrohre (direction-indicator periscope) - see *German Gunnery Material*, 1920 (*op. cit.*), p.5.

[16] *Seydlitz*, ' Experience' (*op. cit.*) f.271.

[17] von Hase (*op. cit.*) pp.80-1.

The German term most commonly associated with rangefinders is 'Basis Gerät' (Bg. for short); literally translated, it means base- or pedestal-gear. Sometimes it evidently refers only to the rangefinder, but at times it also seems to include the range transmitter gear as well.[18] At Jutland, all the range transmitters in *Derfflinger* were connected to an instrument in the armoured fore-control tower; in British intelligence reports, this was called the 'Mittlungs Apparat'. British intelligence believed that this had been introduced in 1916, but von Hase (who gave no name for the equipment) did not mention that it was a new device; thus it remains unclear whether supply had only just begun (in which case it may not have been widely fitted) or whether it was installed in most of the big German ships. This instrument must have been both elaborate and ingenious, since not only was it capable of calculating the average of as many as eight ranges received, but the 'Bg. Officer' in charge of the instrument could switch out of the calculation any ranges which appeared to be anomalous;

> ...thus the average of the ranges given by all the instruments could be read off at any time. When the action began, this range was given to all the guns by the gunnery officer.

The Bg. Officer also reported 'the change of range per minute calculated from the difference of the range-finder readings'.[19]

Like the Dreyer time-and-range plot, the 'Mittlungs Apparat' supplied mean values of range and rate. Near the end of the War, the British were aware that:

> When it became known in the German Navy that plotting was carried out in our Service, experiments were made with 'True course and speed' plotting. The results however, proved unsatisfactory and plotting was abandoned.[20]

All the post-war inspections of German ships concluded that there was no room for plotting tables in their transmission stations[21], while nothing in the translated German sources used here contradicts the conclusion that neither rate nor course plotting were used in their control system.[22]

[18] von Hase, p.79. *German Control of Fire*, 1917, p.16. *Seydlitz*, 'Experience', p.272.
[19] von Hase, pp.79, 131-2 and 144. *Information from PoWs*, 1918, p.16 and Plate 3. See also *Interned German Vessels*, 1919, p.8
[20] *Information from PoWs*, 1918, p.14.
[21] *Interned German Vessels*, 1919, pp.8, 18, 27 and 35.
[22] On the basis of the German report of their firing practices in 1913-14, a 1917 intelligence report concluded: 'Plotting is carried out but it is believed that it is not relied on to the same extent as in the rangefinder'. However, the German report refers to curves made after a firing run to check gun ranges against actual ranges obtained from course plots: *German Control of Fire*, 1917, pp.11 and 21.

Thus the 'Mittlungs Apparat' was an alternative source to the EU-Anzeiger for the range-rate to set on the range-clock. These older instruments for keeping the range-rate 'had already been fitted all over the ship' when *Derfflinger* fought at Jutland. von Hase described only one means of calculating deflection, a new instrument of which one was positioned in her fore-top. Called the Z 31 EU/SV Anzeiger, it had been designed, by Commander Paschen of the *Lützow*, to give both range-rate and deflection. Although, as discussed in the next section, its constructional details differed considerably from the British Mark VI Dumaresq, it employed the same vector-based principles and approximations. Paschen's instrument made better use of the disc by incorporating curves for converting speed-across into gun deflection corrected for range and drift.[23] On the other hand, while it did not require gears to keep the inclination constant during a turn, it lacked the compass rings which allowed the inclination to be corrected once a turn was complete. Thus it appears to have relied even more on the assumption that engagements would be fought only with low bearing-rates. In any case, near the end of the War, British intelligence concluded that the Germans used a separate instrument (though one also based on the same principles as the basic Dumaresq) for finding deflection corrected for wind and drift; although no details of this instrument were given,[24] if it was like the EU-Anzeiger, it did not have any mechanical aids to deflection-keeping through a turn. Since Paschen's instrument was new in *Derfflinger* at Jutland, it may only have been supplied to Hipper's ships at the time of the battle, while the intelligence reports suggest that it may never have been made widely available.

In the turrets, by following their pointers, the trainers and sightsetters kept the turrets on the target and the sights set with the latest predicted range. Thus the gunlayers were able to aim continuously.

> In spite of the rapid motion of the ship the gun-layer must make it his business to see that the sight of the gun is *always* kept trained on the enemy...shooting on a rolling ship was one of the most important feature of our crews' training on the high seas.[25]

In the light cruiser *Breslau*, the gunlayers' continuous aim was sufficiently precise that all the guns could be fired simultaneously with a master electric key; however, the gunlayers preferred firing their own pieces to a gong[26] and, for the heavy guns, this was probably the

[23] von Hase, p.131. Padfield, *Guns at Sea*, pp.228 and 250.
[24] *Information from PoWs*, 1918, pp.16-17.
[25] von Hase, pp.82-3.
[26] *Information from* PoWs, 1918, p.19.

more practicable method. However, as the Royal Navy were well aware by early 1915, even when the actual firing was left to the gunlayers, the German ships usually fired salvoes with the individual shots close together in time and space; indeed, reports written after the Battle of the Dogger Bank assumed that the Germans had fired by director and suggested that the spread had been too small.[27]

German spotting to find the target used brackets, but slightly differently from the Royal Navy. Attempts to estimate the distance over were forbidden but:

> It is desirable that we should train our assistant observers to such an extent that when short shots occur they will be able to tell the fire commander with certainty what size of bracket will suffice.[28]

The importance given when straddling to keeping about a quarter of shot falling short has already been mentioned; as well as verifying that the gun range was correct, the shorts also disrupted an opponent's fire (as *Lion* found to her cost at the Dogger Bank). Spotting was assisted by electric time-of-flight indicators - the translation of von Hase's book calls these 'hit-indicators' - which sounded buzzers in the top, control and TS when the salvo was due to fall; these seem to have been effective though unreliable.[29] Contrary to British assumptions after Jutland, the German sources all indicate that, to find the target, they fired single salvoes, spotting each before firing the next. Range-taking continued between salvoes and was used to check the rate. However, as von Hase's account of Jutland shows, once the target was straddled, a much higher rate of fire was used.[30]

EU/SV ANZEIGER

The instrument as illustrated by Padfield is shown in Plate 53; it is set for a target abaft the beam on a diverging course at less than 90° to own ship's course. The following description of its components and operation are deduced from the illustration, its caption and the general vector principles which apply to all Dumaresq-type instruments.

SU is a bar which was probably graduated for speed-across; the large block sliding on this bar was displaced from the centre of the instrument by a distance proportional to speed-across. The bar EU was calibrated in range-rate; it was free to slide in the block, at right angles to the SU bar. The slider EF was set to own speed.

[27] Brock to VAC, 1st BCS, 26 January 1915 in ADM 137/305. Beatty, 'Notes re Lessons Learned from Action on January 24, 1915' in Brian Ranft (ed.) *The Beatty Papers, Volume I* (Aldershot, 1989) p.225.
[28] *German Control of Fire*, 1917, p.11.
[29] von Hase, p.134. *Seydlitz*, 'Experience' (*op. cit.*) p.272 for breakdown soon after engaging at Jutland.
[30] *German Control of Fire*, 1917, p.11. von Hase, pp.84, 145, 148-9 and 160.

The EU bar was pointed at the target: though sighting vanes are not shown. At one end, it carried a circular dial with a diagonal slot. The bar sliding in this slot represented the enemy ship. The dial was rotated so that an angular scale around its circumference indicated the inclination. This must have required a pointer on the end of the EU bar i.e. GL should be on this bar rather than on the dial. A scale of enemy speed was marked on the top of the enemy bar, the enemy speed being indicated by the pointers GF. The scale must have been graduated such that the speed was proportional to the distance from GF to the end of the bar pivoting on the pin dropping down from the own-speed slider.

Because the rate could be read off the EU scale, the main dial could be graduated with curves of deflection SV (expressed in knots) and target range E. The indicator AD, attached to the block and running parallel to the centre-line of the EU bar, was displaced from the centre of the main dial by an amount proportional to speed-across. The intersection of this indicator with the appropriate range line lay on or near to a deflection line; thus the deflection could be read off, if necessary interpolating between the curves.

The satisfactory operation of this instrument must have depended on the block and EU slider both being free to move with minimal friction. Initially, it was probably set by first putting own speed on EF: then rotating the main dial until the EU bar was pointing at the target: and finally moving the block and EU-bar around until the correct enemy course and speed were showing on the enemy dial. Assuming that own course was constant, correct rate-keeping required that the angle of the enemy bar to the fore-and-aft line (θ) remain constant as the target bearing changed; this implies some sort of clamp to prevent the enemy bar from rotating about the pin on the own-speed slider. However, the design as illustrated does not seem to have such a clamp, nor, indeed, arrangements for clamping own and enemy speeds. Perhaps the instrument was not intended as a rate *keeper* but only as a rate *calculator*.[31] However, it seems more likely that clamps were provided, but that they were omitted to simplify the diagram; then, as the main dial was turned to keep the EU bar on the enemy, the bar and block could slide to register the changes in speeds along and across. If own speed changed, the new values could be set on EF.

[31] The absence of sighting vanes could support this conclusion.

While own course remained constant, the instrument could then keep the rates as accurately as the settings of enemy course and speed allowed. If the 'Mittlungs Apparat' gave a different rate from that indicated, or spotting showed that the range-rate or deflection were incorrect, the enemy bar could be unclamped, the rates corrected, then the bar reclamped with the new values of enemy speed and inclination. This capability (the equivalent of the British 'cross-cut') is implicit in the design of the instrument, but it must be emphasised that the sources consulted do not mention its being used in this way.

If own ship altered course in conditions giving a low speed-across, the inclination remained nearly constant, although the angle between courses changed considerably. To reproduce these effects, it would have been necessary to release 'the angle-between-courses clamp' and clamp the whole enemy dial to the EU bar so that the inclination could not change. Once again, the existence of this 'inclination-clamp' can only be inferred from the theory of this type of instrument. If the inference is correct, then the EU/SV Anzeiger was based on the same approximation used in the British Mark VI Dumaresq. However, since the German instrument had no compass rings, it would have been more difficult to correct the inclination errors after a turn made when speed-across was high.

PRACTICES

After the report of the 1910 practice, the Royal Navy apparently received no further information on German ranges until, soon after the War began, they obtained full details of the practices conducted in 1912-13; this information was promptly copied and printed for circulation in December 1914.[32] It showed that the series of practices had begun for the capital ships in October 1912 with 'Long-range Firing under easy Conditions'. Runs by the battlecruisers used a target 8 x 60m (26 x 197 feet) towed at only 2 knots; the firing ship proceeded at 12 knots, initially on a parallel course but with a two-point turn about half way through. Ranges were from as little as 6,250 yards (*von der Tann*: 36.1% hits on the target) to 8,100 (*Moltke*: 15.6% hits). 'Long-range Firing under difficult conditions' used similar ranges. Targets (sometimes two at once) were towed at 4-5 knots and some exercises included concentration and changing target. During a run by *Ostfriesland* at 14 knots with a 2 point turn, the single target also altered course by 2

[32] Admiralty War Staff, Intelligence Division, *Germany. Results of Firing Practices, 1912-13*, December 1914, ADM 137/4799. The following is based on the tables on pp.14-15, 24-27, 34-5 and 44-53.

points, though the rate was very low; at ranges from 7,650-7,850 yards, 17.5% hits were made. In contrast, *Westfalen* approached the target more steeply, the range falling from 8,300 to 5,700 yards at some 325 yards per minute; she also altered by 2 points but also increased speed from 12 to 14 knots. She made 5.1% hits.

Between April and July 1913, nearly all the fully worked up German battleships and battlecruisers carried out practices which are noteworthy in two respects; the ranges were long, especially when full charges were used: and the targets were moored ships, the old *Sachsen*, *Bayern* and *Oldenburg*.[33] Thus the Imperial German Navy gave most of its heavy ships the opportunity to observe the effects of shots falling on and around actual ships: and to do so at ranges which taxed their skills to the limit. For example, *Ostfriesland* steamed at 15 knots, which gave an average rate of 250 yds/min. as the range fell from 15,100 to 13,000 yards; she made only one hit from 36 rounds (2.8%). *Posen* and *Rheinland*, at 12 knots, concentrated on one target at ranges from 16,000 down to 13,900 yards; with the rate of about 325, they also each made one hit from 36 shots. Both ships fired with full charges. The new *Kaiser* and *Friederich der Grosse* used only 'large practice charges' but their ranges were, nevertheless, from 14,100 to 12,250 yards; rates were low and they made 11.4 and 9.4% hits, respectively. *von der Tann*, under similar conditions, scored 10.7% hits at 13,250-13,650 yards. In all long-range firing at ship targets, even when concentrating, the rate of fire per gun always lay between 1.1 and 0.7 rounds per minute; this is equivalent to a salvo every 27-43 seconds. These high firing rates suggest that, even in 1913, the Germans were already breaking into rapid fire as soon as they had straddled their targets.

By 1917, the British had also obtained copies of German reports on the Firing Practices for 1913-14. Significantly for the Dogger Bank action, one of the schemes of firing in the long range practice was: 'A running fight from the weather position'.[34] However, this information was, almost certainly, not available to Beatty in January 1915, while the report on the 1912-13 firings may not have arrived in time to warn him to

[33] Four *Nassaus*, four *Helgolands*, *Kaiser* and *Frederick der Grosse*, *Moltke* and *von der Tann* took part in the practice. *Goeben* was in the Mediterranean; the remaining three *Kaisers* commissioned May-August 1913. Erich Gröner, revised Dieter Jung and Martin Maass, *German Warships 1815-1945, Volume I* (London, 1990) pp.8,9,26 and 55. The sketches illustrating *Germany. Firing Practices 1912-13* (*op. cit.*) show three target ships moored in line.

[34] *German Control of* Fire, 1917, p.10. Admiralty, *German Navy, Part IV Sections 1, 2 and 4, Gunnery Information*, November 1917 (C.B. 1182E) p.27, Ca 0105, AL.

expect accurate fire from Hipper's ships at very long range; the post-action reports all suggest that this was an unpleasant surprise.

APPENDIX XXV

RANGEFINDER ACCURACY

BRITISH RANGEFINDERS

Before the battleships of the *Queen Elizabeth* class joined the Fleet, all rangetaking by the Royal Navy's battleships and battlecruisers depended on 9-foot Barr and Stroud FQ2 coincidence rangefinders. In theory, the uncertainty of observation for these instruments was 85 yards at 10,000 yards, increasing to 190 yards at 15,000 yards.[1] However, in service conditions and especially in action, these random errors could be much larger. In 1913, *Thunderer*, taking eight ranges per minute with three rangefinders, observed an average spread of 300 yards at 8,000 yards, 700 yards at 9,800 yards (*Vanguard* obtained 23 ranges in 7 minutes from the rangefinder on the Argo mounting).[2] Earlier that year, Dreyer and Usborne had warned that, at longer ranges: 'a single range observation may [be] at 16,000 yards easily as much as 600, 700 or even 800 yards from the truth':[3] though they did not indicate whether these figures included systematic errors as well as the spread due to random errors. Nonetheless, after the Dogger Bank action, Dreyer declared that:

> An inspection of a few of the Rangefinder Plots of the Fleet leads one to believe that excellent results can be obtained roughly speaking up to 15,000 yards in clear weather, and good results from 15,000 to 17,000 yards and fair above that.[4]

[1] *The Barr and Stroud Rangefinders* issued by Barr and Stroud ... Glasgow, 1906, p.19, Ja 190, AL.
[2] 'Summary of Results': *Thunderer*, 'Report on Firings carried out at "Empress of India" 8 November 1913': and *Vanguard* to C.-in-C., Home Fleets in 'Gunnery Practice at Sea: Sinking of HMS Empress of India 4/11/13' in ADM 1/8346, PRO.
[3] F C Dreyer and C V Usborne, *Pollen Aim Correction System. Part I. Technical History and Technical Comparison with Commander F.C. Dreyer's Fire Control System*, printed May 1913, p.19, P.1024, AL.
[4] 'A few notes on the determination of the most advantageous range at which the Grand Fleet should engage the High Sea Fleet', n.d. but probably 1915 in DRYR 1/3, CC.

At Jutland, *Iron Duke's* Commander(G) noted: 'Error [spread] reported by Rangefinder Plot was 500 yards. Range 11,000 yards'.[5]

Later in the War, the Grand Fleet were informed:

> An examination of rangefinder plots obtained at full calibre firings during the third quarter of 1917 shows that small rangefinder spreads were the exception, and that the gun range in many cases differed from the mean of the rangefinders by as much as 1000 yds. In more than one instance, an individual rangefinder altered its divergence from the gun range by 2000 yds. during the firing. Rangefinder rates on the whole were good, but in some cases all rangefinders of a ship indicated a rate of 200 to 300 yds. per minute in error.
> ...for want of a better explanation, these errors have been attributed to refraction, *i.e.* the bending of the rays from the target to the rangefinder, due to the opacity of the atmosphere, smoke, or light effects.

In almost all of the quoted examples (from both 9- and 15-foot rangefinders), the errors, which did not exceed 1,000 yards, were high.[6] However, equally large low errors were observed on another occasion, though these were obtained only with the ship's 15-foot instruments, while the 9-foot rangefinder in the foretop gave much better results. These phenomena were investigated during and after the War; the tentative conclusion was that they were due to a combination of the effects of atmospheric refraction and temperature, aggravated by uneven heating of the rangefinder tube, if the instrument was in direct sunlight.[7]

During post-War trials aboard the destroyer *Winchester*, a consistency[8] of 185-330 yards was obtained with the Barr and Stroud 9-foot FQ2 rangefinder when taking about four ranges per minute between 12,500 and 14,000 yards. These results were obtained during high-speed runs, so the conditions for rangetaking were more difficult than on a large ship, even though the rangefinder was on a special anti-vibration mounting.[9] The tests used an experimental rapid method of rangetaking, which 'only very slightly increased' the figure attainable by the usual method, which 'has been found to provide just over four ranges per minute under vibrationless conditions....Under conditions of bad or even moderate vibration...only about 2 ranges per minute'

[5] Commander Blake, 'Notes made in the...Gun Control Tower' in ADM 137/302, PRO.
[6] '312. Rangefinder Errors', *Grand Fleet Gunnery and Torpedo Orders*, p.198, ADM 137/293.
[7] Admiralty, Technical History Section, 'Fire Control in H.M. Ships' (TH23), p.33 in *The Technical History and Index, A Serial History of Technical Problems dealt with by Admiralty Departments*, 1919, AL. Admiralty, Gunnery Branch, *Progress in Gunnery Material 1921*, p.9, ADM 186/251 and *Progress in Gunnery Material 1922 and 1923*, ADM 186/259, p.53.
[8] Assumed to be half the spread: see below.
[9] *PGM 1922-3* (*op. cit.*) p.38.

GERMAN RANGEFINDERS

Until 8.2-metre rangefinders were installed in the turrets of *Bayern* and *Baden*, nearly all German battleships and battlecruisers continued to rely on Zeiss 3-metre instruments. The tube of the turret model was under the roof, with prismatic objectives protruding through it. On the control tower, the main tube of the rangefinder rotated above the roof, while extension tubes brought the images down to the rangetaker in the tower. Because of the errors arising only in the prismatic ends, the turret rangefinders may have needed continual adjustment[10] and most reliance seems to have been placed on the control tower rangefinder;

> ...in the *Ostfriesland*, it was the practice to station a very skilful observer [at] the rangefinder in the fore control tower, and to use the ranges taken by him for purposes of control....[11]

However, von Hase made no such distinction; he claimed that 'there was seldom a variation of more than 300m. between any of the rangefinders even at the longest ranges' and that they 'gave excellent results up to distances of 200 hm.' (20,000 m or 21,850 yards). An indication of the expected accuracy is that the range scales were graduated in 100m. intervals from 10,000 to 15,000 m. and in 200 m. intervals to 20,000 m.[12] However, if the post-War recollections of Lieutenant-Commander Renken of the German Navy were correct,

> ...at the Battle of Jutland the "Derflinger" [*sic*] carried a 6-metre *coincidence* type rangefinder on the roof of the gun turrets [*sic*].
> This instrument was constructed by Messrs. Zeiss, but it was not very satisfactory, being affected by temperature and being defective for definition. It was placed in "Derflinger" merely to satisfy Commander Von Hasse [*sic*], who is stated to be a persistent officer and an advocate of as many rangefinders as can possibly be mounted.
> Commander Renken did not think this particular instrument could have been of much real service on account of its imperfections and its exposed position.

[10] Naval Staff, Intelligence Department, *Report on Interned German Vessels. Gunnery Information*, February 1919, pp.8, 17 and 34-5, ADM 186/240. Naval Staff, Intelligence Division, *Reports on Interned German Vessels, Part V Gunnery Material*, October 1920 (C.B. 1516E), pp.7 and 8, ADM186/243. *Bayern* and *Baden* had 8.2m. turret rangefinders. The Royal Navy also believed that the *König* class had 5 and 8m rangefinders and that other ships carried '3m or larger': Royal Navy, *German Warships of World War I* (London, 1992) pp.4, 7, 10 and 24: this reproduces Confidential Books dating from 1918.

[11] *Seydlitz*, 'General Experience', f.272 in *Jutland, Later Reports*, f.271, ADM137/1644. Naval Staff, Intelligence Department, *German Gunnery Information Derived from the Interrogation of Prisoners of War*, October 1918 (C.B.01481), p.18, Ca 0108, AL.

[12] Georg von Hase, *Kiel and Jutland* (London, 1921) pp.148 and 79. *Information from PoWs*, 1918 (*op. cit.*) p.22. The latter stated that, between 15,000 and 17,500m. the graduations were at 150m. This is almost certainly an error and it is best to assume a 200m division from 15,000 to 20,000m. From 20,000 to 25,000m, the divisions were 500m

Renken presented himself as a strong supporter of coincidence rather than stereoscopic rangefinders, so he does not seem to have had any motive (other than an apparent dislike of von Hase) for criticising this particular rangefinder more severely than it deserved. Of course, von Hase was under no obligation to mention experimental rangefinders in his book but, in the aftermath of defeat, he may also have been inclined to exaggerate the accuracy of his standard equipment. If his accuracy figures for the Zeiss 3-metre stereoscopic instrument were correct, it is understandable that the German Navy were in no hurry to introduce a longer instrument: and general satisfaction with the stereoscopic principle might have been expected.

In fact, Renken claimed that opinion in his navy was divided and that:

> ...all the officers he knows, with the exception possibly of Captain Bode, are now strong advocates of coincidence rangefinders...

He also stated that trials between a Barr and Stroud FQ2 9-foot and a Zeiss 3-metre, held by the German Admiralty in 1912, had demonstrated the superiority of the Barr and Stroud instrument. However, he was giving his information to Dr J W French, a director of the Glasgow firm, though the latter was careful to acknowledge that:

> As the opinions of Commander Renken are favourable to Barr and Stroud, the writer...wishes to emphasise his practical interest in the subject and the possibility that his impression may unwittingly be biased.
> It should be remarked, however, that Messrs. Barr and Stroud have experience of both types of instruments, the firm having constructed stereoscopic rangefinders as large as any made by Messrs. Zeiss.

It is even possible that Renken was deliberately misleading his interrogator. However, French had earlier reported on the opinions of Captain Bode, who had made no attempt to hide that he was 'an enthusiastic supporter of the stereoscopic rangefinder' and had claimed that he had 'been responsible for the retention of stereo rangefinders against much opposition' from officers whose principal objection was 'the small proportion of observers available and the difficulty of checking their work'.[13]

COMPARATIVE TRIALS

After the War, the Royal Navy conducted several series of comparative trials involving rangefinders from Barr & Stroud, Thomas Cooke and Zeiss. Initially, in 1921, opinions were still open and it was decided to manufacture a prototype duplex rangefinder (for use in the new design of director control tower) containing both

[13] *German Gunnery Material*, 1920 (*op. cit.*) pp.8-9.

coincidence and stereoscopic instruments in one tube. However, by 1923, the trials had not demonstrated any clear-cut superiority of one type over the other. The results of the fourth series are summarised in the following table, which gives average figures for the long-term 'accuracy' (based on ranges taken over periods of weeks and months) and the short-term 'consistency' (a measure of variation within single sequences of readings). The data are derived from about 30,000 observations taken from June to November 1922 of fixed objects (at ranges from 15,770 to 20,530 yards) and moving targets at ranges greater than 10,000 yards.[14]

Model	Maker	Length	Type	Accuracy (yards)		Consistency (yards)		Cuts per minute
				Fixed	Moving	Fixed	Moving	
FX2	B&S	30-ft.	Coincidence	344	583	104	190	4.9
FG4	B&S	30-ft.	Stereo	336	671	78	234	4.8
FT24	B&S	15-ft.	Coincidence	294	618	115	305	4.6
ZS	Zeiss	7.8-m. 25.6-ft.	Stereo	285	490	144	298	4.6

Notes. 1. The report does not give the actual formulae used to calculate accuracy and consistency. Both were expressed in yards.
2. The consistency for a single sequence of static ranges was probably the mean of the absolute values of the deviations of the individual ranges from the mean range of the sequence; the consistency figures in the table were then the average of the consistencies from many sequences.
3. The accuracy figures in the tables for fixed objects were possibly calculated as the mean of the absolute values of the deviations of the sequence means from the true range (after correction if the instrument had been adjusted deliberately to read high or low).
4. Ranging sequences were plotted but the report does not state how accuracy and consistency figures were obtained when objects were moving and ranges changing.

The Zeiss rangefinder was outstanding only in its long-term stability, which was attributed not to its stereoscopic property but to its more efficient infinity adjuster and to extensive use of Invar (an alloy with a very low coefficient of thermal expansion). The report concluded that 'there is little to choose between the two types of rangefinder, provided the operators observing are equally skilled in rangetaking', although it was accepted that 'under certain circumstances, the stereoscopic rangefinder can obtain ranges when the coincidence instrument cannot', notably from 'a ship almost enveloped in smoke'.

> On the other hand, the stereo rangefinder has certain disadvantages:-
> ....
> ...The temperamental and physical condition of a stereo operator plays an important part in rangetaking. Cases occurred in two German ships during the late war where in consequence of a salvo hitting, every stereo rangetaker had been rendered mentally

[14] *PGM 1922-3*, pp.26 and 42-9.

> incapable of taking a stereoscopic range.[15]
> ...The limited field of selection and the difficulties arising in training and supervising stereo operators.[16]

These objections proved decisive.

> It has been decided that the F.X. type of coincidence rangefinder...is better suited for Naval Service than any other type, and the future policy will be to supply the F.X. type...wherever conditions of space, etc., admit. This policy will be followed out [*sic*] in the case of the "Nelson" and "Rodney".
> The F.X. type of rangefinder was produced with the idea of improving rangetaking under poor conditions of light, its main feature being the fitting of enlarged optical parts for this purpose.[17]

However, in the middle of the next World War, even the Royal Navy's latest rangefinder handbook admitted that:

> Most foreign navies use the stereoscopic method, but, as a result of trials, the British Navy have so far preferred the coincidence rangefinder.[18]

UNITED STATES NAVY

In June 1917, Commander Richard T Down RN attended a series of liaison meetings with the U S Navy in Washington. He reported:

> Without exception they express the most profound astonishment in our placing any reliance on the 9 ft. rangefinder except as a navigational instrument. They maintain that it cannot be considered as accurate for practical gunnery purposes at ranges over ten thousand yards.-

That a	12-ft. rangefinder is accurate only	up to		12000 yds.
"	15 "	"	"	15000 "
"	18 - 20 ft. "	"	"	18 - 20000 "

Unfortunately, Down did not define numerically what was considered 'accurate'. He also stated that the U S Navy preferred Bausch & Lomb to Barr & Stroud instruments and, at the instigation of the DNO, Frederic Dreyer, examples of the former were purchased for the Royal Navy;[19] however, comparative trials by *Excellent* and *Warspite* found in favour of the British supplier, though on grounds relating principally to construction;[20] any difference in accuracy was not mentioned.

[15] One of these cases had been cited by Renken to French (*German Gunnery Material*, 1920, p.9). If this was disinformation, it had the desired effect.
[16] *PGM 1922-3*, pp.51 and 56-7.
[17] *ibid.* p.39. The FM2 duplex coincidence rangefinders installed in *Nelson* and *Rodney* were designated FM2: *Handbook for Naval Rangefinders and Inclinometers, 1943. Volume I* (p.50) and *Volume II* (p.5), AL.
[18] *Rangefinders and Inclinometers, 1943. I* (*op. cit.*) pp.38-40.
[19] Commander Richard Down to C.-in-C. North America and West Indies, 27 June and 22 July, 1917 and DNO's minute, 8 August 1917 in 'United States of America. Naval Co-operation 1918 I', ADM 137/1621
[20] *Technical History*, 1919 (*op. cit.*) p.35.

Later experience in the U S Navy suggests that the Royal Navy had been right in 1921 to propose that both coincidence and stereoscopic rangefinders should be available: and that, in both World Wars, British ships were at some disadvantage in relying solely on the coincidence type. During the American Long Range Battle Practice of 1939-40:

> "...ships were firing into a bad sun glare [and a] surface haze about 200 feet deep which caused a mirage effect on the horizon". Under these conditions, both *Tennessee* and *Maryland* found that the usually more dependable stereo range finders were less accurate than the coincidence types.
>
> *Tennessee* used two coincidence type 33 foot Mark XXII rangefinders and one 15 foot Mark XXXVIII stereo rangefinder during the shoot, noting that "Normally the latter is the ship's best range finder.[21]

CONCLUSIONS

Do these sources permit a comparison between the accuracies of the 9-foot Barr & Stroud FQ2 coincidence rangefinder and the Zeiss 3-metre stereoscopic instrument?

Firstly, the available figures for the FQ2 indicate that a spread of about 500 yards was attainable in good conditions, but only up to 15,000 yards or so. Secondly, Dr French's conversations and the performance in comparative trials of the Zeiss 7.8-metre instrument suggest that von Hase's claims (a spread of seldom more than 300m. up to distances of 20,000m.) were exaggerated. However, while the accuracies of the Barr & Stroud 9-foot and Zeiss 3-metre may well have been comparable below 15,000 yards, the German instrument probably maintained its accuracy better at greater ranges. And there is no reason to doubt that, in the hands of a steady rangetaker gifted with stereoscopic vision, it was much better at ranging on a target almost shrouded in smoke.

These conclusions assume equally well trained rangetakers.[22] The specially selected operators of the stereoscopic German instruments needed intensive training,[23] and the accurate shooting of Hipper's ships at the Dogger Bank and Jutland leaves little doubt that it was provided. In contrast, as discussed in Chapters 3 and 6, there must be doubts about the general standard of training of the Royal Navy's rangetakers, though some squadrons (the 2BS), or even individual ships within a squadron (*Princess Royal*), were evidently better practised than others.

[21] W J Jurens, 'The Evolution of Battleship Gunnery in the U.S.Navy, 1920-1945' in *Warship International*, Volume XXVIII, No.3, 1991, pp.252 and 269 (reference courtesy Professor Andrew Lambert).
[22] Comments by Captain Peter Grindal, RN on the previous draft of this appendix.
[23] Peter Padfield, *Guns at Sea* (London, 1974) p.259.

APPENDIX XXVI

THE RUN TO THE SOUTH: NOTES

1. CHARTS

The charts cited in the main text[1] and in Note 8 are from a series: 'Prepared by the Operations Division of the Naval Staff under the Superintendence of Captain J.E.T. Harper MVO, RN and produced by the Hydrographic Department'. The history of Harper's record until its eventual publication in 1927 is described in *The Jellicoe Papers, Volume II*:[2] and in Captain Roskill's *Beatty*.[3] The Record and track charts were completed on 2 October 1919.[4]

The chart for the 'First phase 2 p.m. to 3.40 p.m.' shows *New Zealand* having turned through 16 points to starboard from 3.34 to 3.38 and having half completed the second 16-point turn to port at 3.40. This suggests that she steadied on course E no earlier than 3.42.

2. HIPPER'S FIRE DISTRIBUTION SIGNAL

The German 'Summary of Messages' contains the signal 'Distribution of fire from the left' with a time received of 3.30. However, it is listed between signals received at 3.37 and 3.40.[5] '3.30' is almost certainly a misprint and should read either 3.39 or 3.40.

[1] 'Battle of Jutland. Battle Cruiser Action. First Phase 2 p.m. to 3.40 p.m. May 31st 1916', BTY 24/49 NMM.

[2] A Temple Patterson (ed.) *The Jellicoe Papers, Volume II* (Navy Records Society, 1968) pp.399-404 and 458-490.

[3] Stephen Roskill, *Admiral of the Fleet Earl Beatty* (New York, 1981) Chapter 15.

[4] *Jellicoe Papers II* (*op. cit.*) p.464.

[5] V E Tarrant, *Jutland. German Perspective* (London, 1997) Appendix 10, 'Summary of the More Important Wireless Messages and Visual Signals Relating to the Battle of Jutland'; the 1SG signals are in Appendix XXVII.

3. BEARINGS AND RATES ON THE APPROACH

The target bearings recorded in *Lion* and *Princess Royal* from the turn E at 3.30 until fire was opened were as follows. These are bearings relative to ship's head. R stands for Red i.e. the bearings are all off the port bow.[6]

Time	*Princess Royal*	*Lion*
3.30	R30	R20
3.33	R23	
3.35		R32
3.39	R20	
3.47½		R42
3.48	R42	R45

It is difficult to explain why *Lion's* target bearing at 3.35 was as high as R32. Her course was E until at least 3.43, after which she turned 2 points onto ESE.[7] Since speed-across was very low throughout (see below) the target *compass* bearing remained almost constant. Thus any change in relative bearing from ship's head would have been due only to course changes. Since the bearing was R42 at 3.47½, it should have been R20 until *Lion* began her turn at 3.43.[8] The following calculations assume this value, which is the same as *Princess Royal's* at 3.39. Perhaps *Lion* veered momentarily to the South by one point around 3.35; this would certainly have helped *Princess Royal* in avoiding the flagship's smoke.

At 3.42, when *Lion* obtained a range of 20,000 yards, the courses and bearings were as shown in Fig. XXVI.1 overleaf. The 1SG had completed its 15-point turn at about *3.39*. It is therefore unlikely that they had yet worked up to the 18 knots then ordered by Hipper;[9] a speed of 15 knots is assumed in the following calculation of the rate.

At 3.42, from equations 2:1 to 2:6:

$$\dot{R} = 33.78(15 \cos 65 - 24 \cos -20) = -548 \text{ yds/min.}$$

(The rate would have been -505 yds/min. had the enemy speed been 18 knots.)

$$x = 15 \sin 65 + 24 \sin -20 = 5.386 \text{ knots.}$$

[6] 'Record of Events during Action of May 31st compiled from Records kept in Control Position and Transmitting Station. H.M.S. Lion' in BTY 6/6. 'H.M.S. "PRINCESS ROYAL", Fore T.S. Record of Action, 31st May 1916' in ADM116/1487, PRO.

[7] *Lion*, 'Record of Events' (*op. cit.*). 'Track of BCF II.0 PM to IX.24 PM, 31/5/16 in 'Jutland. Plans, Diagrams, Track, Charts, Photographs, &c', ADM 137/303.

[8] Two points equals 22½°.

[9] German 'Summary of Messages' (*op. cit.*).

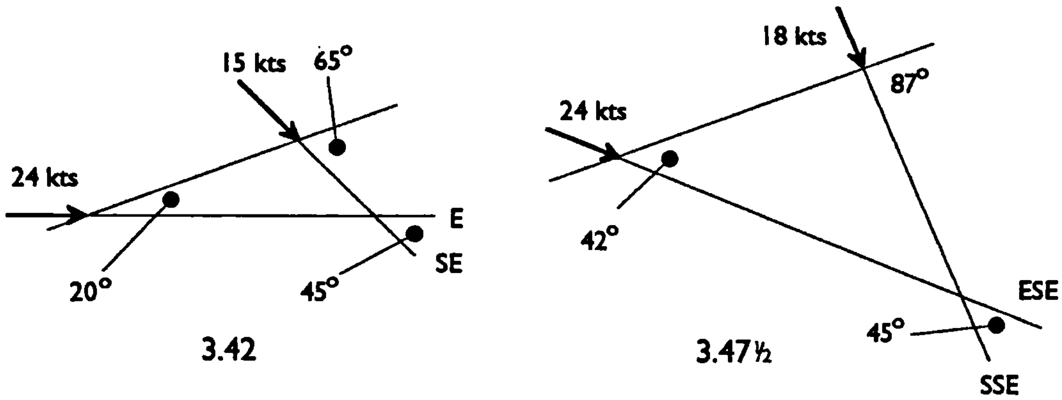

FIG. XXVI.1: ACTUAL OR ESTIMATED COURSES, SPEEDS AND BEARINGS

At 3.47½, when the true range was 16,000 yards and the 1SG can be assumed to have reached 18 knots:

$$\dot{R} = 33.78(18\ \cos 87 - 24\ \cos -42) = -571\ \text{yds/min.}$$

$$x = 18\ \sin 87 + 24\ \sin -42 = 1.916\ \text{knots}$$

$$\dot{\beta} = \frac{1935 \times 1.916}{16,000} = 0.23°/\text{min.}$$

$$\ddot{R} = \frac{1141 \times 1.916^2}{16,000} = 0.26\ \text{yds/min/min.}$$

Thus, especially after the 1SG altered by 2 points to SSE at *3.44*, the speed-across was low while courses were steady. Since *Lion* probably altered course by one point each at 3.43 and 3.46, the angle between courses never varied much from 45°. To estimate the earlier actual ranges approximately, assume that the rate was -548 yds/min. until 3.44½ and then -571 yds/min. Thus the ranges at 3.46 and 3.42 were about 16,900 and 19,100 yards respectively and, at 3.42:

$$\dot{\beta} = \frac{1935 \times 5.386}{19,100} = 0.55\ °/\text{min.}$$

$$\ddot{R} = \frac{1141 \times 5.386^2}{19,100} = 1.7\ \text{yds/min.}$$

Hence the assumption of a near-constant rate is confirmed.

4. LINE OF BEARING

If a course or intended course of ships in line ahead is such that the wind comes from any direction on the non-engaged side, smoke is carried towards the enemy,

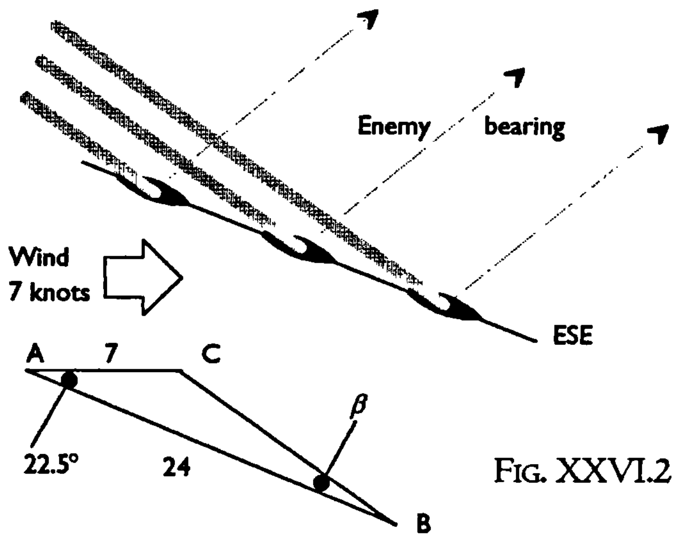

Fig. XXVI.2

resulting in smoke interference. To avoid this, it is necessary to form on a line of bearing inclined on the engaged side; each ship can then steam ahead of the smoke from the ship before it in the line.

Fig XXVI.2 shows three ships on course ESE at 24 knots, with an enemy bearing East and North. In a wind from the West of 7 knots, the smoke is carried towards the enemy at an angle which can be obtained from the triangle of velocities ABC; in the time the ship takes to travel from A to B, the smoke emitted at A is carried by the wind to C.

$$CB^2 = 7^2 + 24^2 - 2 \times 7 \times 24 \cos 22.5$$

$$CB = 17.74$$

$$\frac{CB}{\sin 22.5} = \frac{AC}{\sin \beta}$$

Therefore $\beta = 8.7°$

Fig. XXVI.3 overleaf shows how, by forming a line of bearing NW from the leading ship, all ships on a course ESE are freed from smoke interference. How were Beatty's ships to manoeuvre into this formation from their course E in column?

Firstly, what discretion was allowed to individual ships should they suffer from smoke interference? Battle Orders for the battlecruisers emphasised that:

> ...Much must be left to the initiative and judgement of Captains. They are relied upon to act promptly in battle on their own initiative for dealing with all cases such as the following:-
>
> ....
>
> (d) Hauling out of the wake of next ahead to avoid smoke or backwash. N. B. It is desirable that ships should not haul out more than 1 point, lest they hamper the squadron when turning in succession. If 1 point is insufficient, ships should avoid smoke interference by opening out.
>
> (e) Altering line of bearing from Flag in order to get a clearer arc of fire.
>
> (f) Or any other case in which Captains consider that prompt action is needed, and their movements are such as the Rear Admiral would certainly approve if they could be made known to him beforehand. The chief limitation in these cases is that no

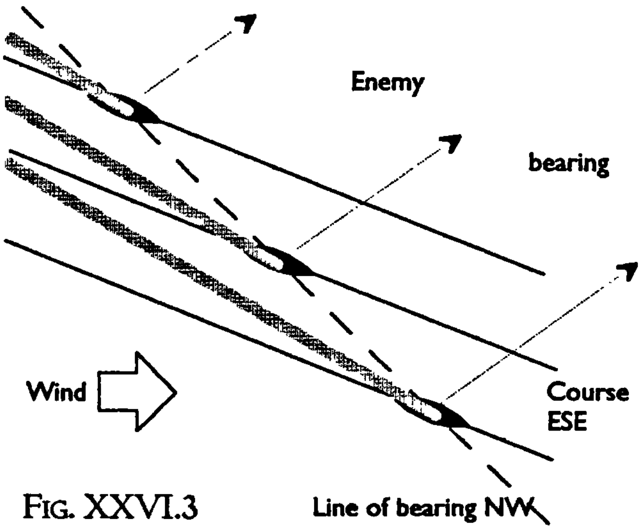

Fig. XXVI.3

movement must mask the fire of other ships, or in any way inconvenience them from a manoeuvring point of view.[10]

While these orders gave sufficient scope for adjustments to relative bearings and distances between ships, they did not, and could not, cover major changes of formation, which required clear signals from the flagship.

The following analysis of the signals made from *Lion* has benefited greatly from advice concerning fleetwork in general and line-of-bearing manoeuvres kindly provided by Captain Peter Grindal RN,[11] who emphasises that:

> A key point which needs to be borne in mind in consideration of fleetwork manoeuvres is which ship is the guide of the formation at any instant. It is the responsibility of each ship to achieve and maintain her correct range and bearing (true or relative as appropriate) from the *Guide*, not the next in line....in the absence of other orders from Beatty and Pakenham, the Guide of the 1BCS was *Lion* and of the 2BCS, *New Zealand.* With the squadrons in one formation the Guide would, similarly, be *Lion.*

This last was the situation once the 2BCS had joined the line at 3.42 or shortly thereafter. Then, at 3.43 according to Beatty's Personal Narrative, the signal to 'Form on a line of bearing NW' was hoisted:[12] while both this narrative and the British 'Record of Messages' agree that it was made executive at 3.45. However, the 'Record of Events' from *Lion's* TS shows a one-point alteration to starboard at 3.43 and another starboard turn (its extent unspecified) at 3.46.[13] These must be related to *Lion's* next manoeuvring signal, 'Alter course together to ESE', though its timing is uncertain. In the 'Record of Messages' it is

[10] 'Confidential Battle Orders for 1st BCS', 17 July 1913 in Brian McL Ranft (ed.) *The Beatty Papers, Volume I* (Aldershot, 1989) pp.74-5.

[11] The present author (who must take full responsibility for any remaining errors) is very grateful for this advice and for the many helpful comments on the previous drafts of this chapter and its appendices: Captain Peter Grindal RN to the author, 19 June 2001.

[12] 'Battle of 31st May: Narrative of Events' in 'Action with the German High Sea Fleet, 31st May - 1st June 1916. VABCFs Personal Records', BTY 6/3 (Appendix XXVIII). Appendix II, 'Record of Messages bearing on the Operation' in *Battle of Jutland. Official Despatches with Appendices* (London, 1920) pp.449-50 (Appendix XXVII).

[13] *Lion*, 'Record of Events'. All three sources give *Lion's* first salvo at 3.47/47½ , so, at this stage, their timings are well synchronised.

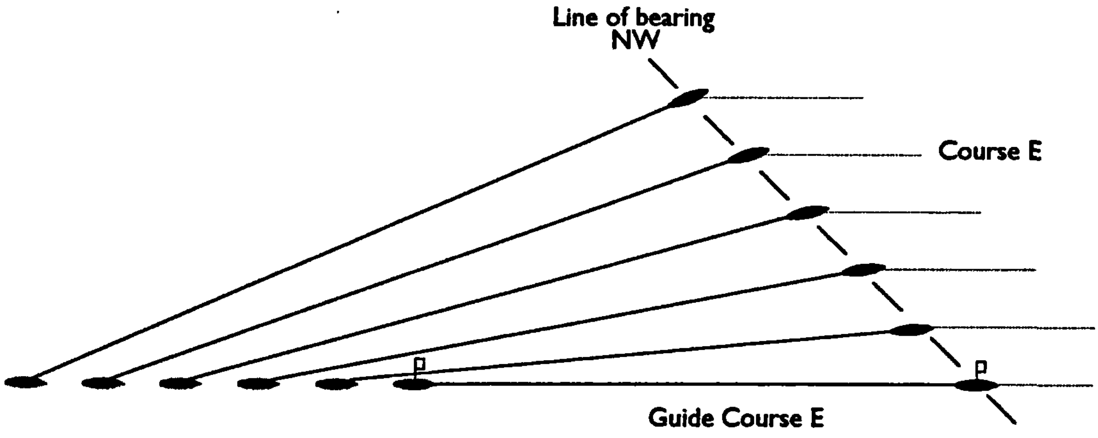

FIG. XXVI.4: FORM ON A LINE OF BEARING NW

the next flag signal and also timed at 3.45. Yet the Personal Narrative puts it two minutes later, in the same hoist as the signal to open fire. How could Beatty's ships have interpreted these signals, made as the flagship turned to starboard to ESE?

At 3.45, the ordered course was still E. Therefore the normal response to 'Form on a line of bearing NW' was for the Guide to maintain her E'ly course and for the other ships to haul out to port and increase speed until they had taken up their new stations (Fig. XXVI.4).[14] If the normal separation between ships (3 cables or about 600 yards) was preserved, this manoeuvre required over 10 minutes, even assuming that *Lion* did not exceed 24 knots[15] and that *Indefatigable* (with the greatest distance to cover) had worked up to 27 knots. This time could have been reduced by larger turns to port (though at the cost of extending the line): for example, to less than 8 minutes if *Indefatigable* had turned by 2 points.[16] But this would have taken her directly towards the German line, further increasing the rate and, in effect, crossing her own 'T'. Thus, whatever the actual stationing courses, forming the line of bearing by turns to port was certainly inappropriate to Beatty's tactical situation.

It is therefore very unlikely that Beatty intended his first signal to be acted on in this way. Perhaps the hoisting of the signal as *Lion* turned to starboard was an indication that something different was required, though such a small turn would not have been easy to see through smoke. However, the second signal made clear that the Guide was (or soon

[14] This and the next figure are redrawn from Grindal to author (*op. cit.*) Figs. 1 and 2.
[15] British 'Record of Messages' (*op. cit.*), signals to 5BS at 4.18 and from Beatty at 3.35.
[16] Times and distances can be calculated using relative velocity triangles.

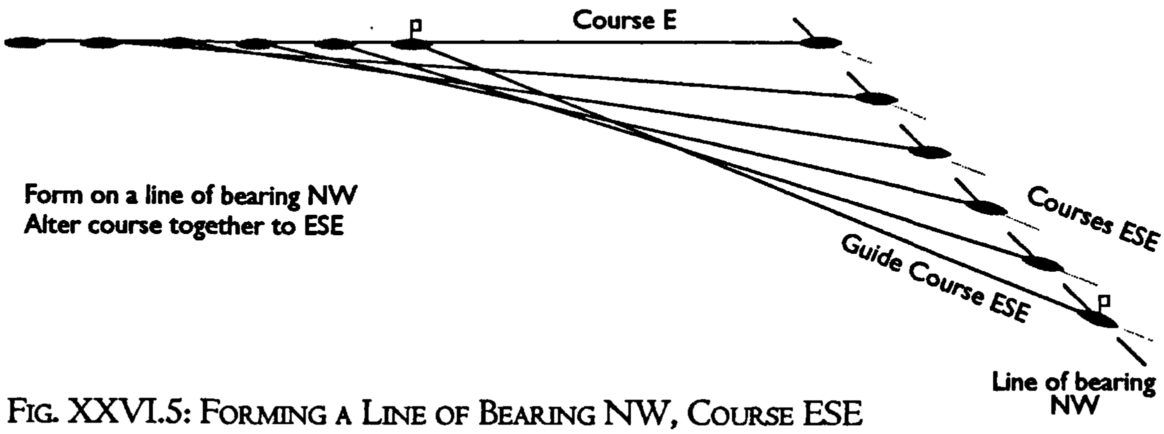

FIG. XXVI.5: FORMING A LINE OF BEARING NW, COURSE ESE

would be) steering ESE. It required the other ships to recalculate their stationing courses, as in Fig. XXVI-5 (which assumes the simpler case of the course signal being received before any ships actually turned to port). As it happened, *Indefatigable* could have held her course E and, with the other courses shown, the line-of-bearing NW could then have been formed in slightly less than 7 minutes. Thus, if perfectly executed, this manoeuvre was capable of achieving the desired change in course and formation - from E in column to ESE on a line-of-bearing NW: but no earlier than 3.52.

In reality, the conditions were hardly favourable for such a complex evolution and, in any case, the line-of-bearing could not have been formed as intended. The smoke which obscured the targets must also have interfered with signalling: while the Germans opened fire at least 5 minutes before the manoeuvre could have been completed. The two signals were made separately, perhaps with as much as two minutes between them. This could have been yet another signalling mistake by Beatty's flag-lieutenant, Ralph Seymour.[17] It was potentially confusing and, the greater the delay before the second signal, the more likely it was that some ships would have altered course to port before having to veer back to starboard. At 3.49, at least 3 minutes before the line of bearing NW could have been established, *Lion* began a series of unsignalled turns to starboard (XXVI-9). If further smoke interference was to be avoided, the new courses required a line-of-bearing swinging ever more E'ly, but Beatty gave no further manoeuvring orders and his other ships were left to use their initiative as best they could. The 2BCS held to the course E until *3.54* and then turned sharply to SSE;[18] thus they probably never

[17] For Seymour's record, see Andrew Gordon, *The Rules of the Game* (London, 1996) p.93 *et seq.*
[18] 'Tracing of track followed by Second Battle Cruiser Squadron...' in ADM 137/303 but originally attached to 'Second Battle Cruiser Squadron. Report on Action of 31st May 1916', 3 June 1916 in ADM

received the two earlier signals. Because of smoke, it is possible that the signal also did not reach *Tiger*, but her courses are too uncertain to give any clear indication one way or the other.

The delays and risks inherent in the two manoeuvring signals made by *Lion* were not even necessary.

> A much neater, quicker and more firmly controlled way of achieving the formation Beatty wanted would have been to turn in succession (a wheel) to SE, which would have formed the line of bearing, using a simple equal-speed manoeuvre, in about 4 minutes at 25 knots. Then, if he really wanted to steer ESE, he could have executed a turn together, taking about a minute, once *Indefatigable* had steadied on SE....[19]

A final point concerns the charts provided by Campbell and Tarrant for the period under consideration, which are very similar to Marder's. They show the line of bearing being established by 3.48, with all ships then turning together to ESE. In the formation of the line of bearing, *Tiger* is represented as maintaining the course E, with the 2BCS turning to port and the rest of the 1BCS to starboard.[20] These courses would have been a permissible response to an order to form line-of-bearing NW, but only if *Tiger* it had already been designated as the Guide instead of *Lion*.[21] No such signal appears in any of the sources.

5. TURRET TRAINING ANGLES

From 3.30 to 3.43, the enemy was only about 20° off *Lion's* port bow. By 3.47-8, the reported target bearings from both *Lion* and *Princess Royal* were R42 (XXVI-3); however, notes made in *Lion's* TS give a bearing of R30,[22] at the very limit of the forward bearing of the after turrets.[23] John Campbell concluded from her ammunition records that *Lion's* initial salvoes were indeed solely from the forward turrets and that *Moltke* was still only 30° off *Tiger's* bow at 3.51;[24] furthermore, a survivor from *Queen Mary* also recalled that she too opened fire with only her fore turrets.[25]

137/302. See further XXVI-12.

[19] Grindal to author.

[20] Arthur Marder, *From the Dreadnought to Scapa Flow, Volume III* (Oxford, 1978) Chart 4. N J M Campbell, *Jutland. An analysis of the fighting* (London, 1986) pp.44-5. Tarrant, *German Perspective* (*op. cit.*) p.79. Gordon, *Rules of the Game* (*op. cit.*) p.114 shows all Beatty's ships turning to port.

[21] Grindal to author.

[22] 'Notes made by Sub-Lieutenant R P Selby in charge of T.S. of HMS Lion...' in papers of Captain R P Selby, 96/20/1, IWM.

[23] Plan 'HMS *Queen Mary* 1913' in John Roberts, *Battlecruisers* (London, 1997).

[24] Campbell, *Analysis* (*op. cit.*) p.39.

[25] *Lion*, 'Record of Events'. *Princess Royal*, 'Record of Action' (*op. cit.*). Campbell, *Analysis*, p.39. Recollections of Midshipman J H Lloyd-Owen (X turret) in M W Williams, 'The Loss of HMS Queen Mary at Jutland'

The 2BCS opened fire at *3.51* but they did not alter course, from E to SSE, until *3.54*.[26] Thus her first six rapid salvoes were fired with a target bearing of about R20 and can have come only from her fore and port wing turrets.

The courses illustrated in Fig. XXVI-5 suggest that it is probable that the after turrets of *Tiger* and *Queen Mary* were at the limits of forward training, so even slight variations in course, or momentary yaws, would have prevented their returning fire immediately. However, this conclusion is less likely to apply to *Lion* or *Princess Royal*.

6. WIND AND VISIBILITY.

> ...the weather was misty in patches, the visibility varying from 12 to 6 miles; wind west, force 3; sea calm.[27]

> The weather was misty in patches, and the visibility was varying from eleven to six miles. The sea was calm and there was a light westerly breeze.[28]

> The day was hazy and fine with practically no wind. I should put the visibility down as between 7 and 10 miles, varying in patches. Smoke also added occasionally to the haziness, but I was rather impressed by the little smoke interference there was.[29]

> At 3.57 p.m. we heard from the *Lion* that they were engaging the enemy....
> The weather at this time was clear, but with patches of thin mist near the horizon, and visibility approximately 16,000 yards; the wind was S.W., force 2, and the sea smooth.[30]

> At [4] p.m....the *Indefatigable* blew up....
> The north-westerly wind was blowing the smoke from the English guns between them and us. As a result of this, their view was often hampered and shooting made more difficult.[31]

> As at [5.20]p.m....the visibility, which had hitherto been good, became less so. The wind had backed from North-West through West to South-West.[32]

> As soon as we opened fire (and by "we" I mean our B. C.'s) the Germans opened fire as well, if not before... whilst our own B. C.'s were only a mile or so from us, the Germans were about 20,000 [*sic*] yards away and against a dark grey background, whilst we were silhouetted against the Western sky.[33]

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in D McLean and A Preston (eds.) *Warship 1996* (London, 1996), p.113.

[26] 'Second BCS Report' (*op. cit.*). H.M.S. "NEW ZEALAND", 'Action with German Fleet 31st May 1916. Record of Ranges, Rates, etc. Compiled from Transmitting Station & Control Top Records' in ADM116/1487.

[27] 'Narrative of...the Gunnery Officer of H.M.S. "Tiger"' in H W Fawcett and G W W Hooper, *The Fighting at Jutland* (London, 1921) p.423.

[28] Admiral Sir Henry Pelly, *300,000 Sea Miles. An Autobigraphy* (London, 1938).

[29] Captain, *New Zealand* to RAC, 2BCS, 'Report of Action of 31st May 1916', 2 June 1916 in ADM 137/302.

[30] 'Narrative from H.M.S. "Indomitable" in *Fighting at Jutland* (*op. cit.*) p.243.

[31] Georg von Hase, *Kiel and Jutland* (London, 1921) pp.153-4.

[32] 'Report by the Commander-in-Chief of the German High Sea Fleet on the Battle of Jutland', appendix to *Battle of Jutland. Official Despatches* (*op. cit.*).

[33] 'The Diaries of Stephen King-Hall' in L King-Hall (ed.) *Sea Saga* (London, 1935) p.451. Stephen

> ...whereas we had behind us to the westward a clear sky and a horizon which silhouetted our ships clearly, the enemy ships were difficult to discern. Behind them to the eastward there was a dull grey sky and a misty horizon; spotting for us was therefore difficult and for him much easier.[34]

7. *LION'S* RANGES

At 3.42, *Lion's* TS recorded a rangefinder range of 20,000 yards, an error of +900 yards on the calculated value (XXVI-3). The rate was estimated by her TS as -300 yds/min., though it was assumed to be falling in magnitude; the previous values were -400 yds/min. at 3.39 and -900 yds/min. at 3.35. At 3.42, the assumption was 'Enemy corse [*sic*] 23 to right' i.e. the inclination was +23°. If the target bearing was then R20, this placed the 1SG on an almost parallel course to the British battlecruisers. It is also possible to calculate the enemy speed (e) which must have been set on *Lion's* Dumaresqs.

$$-300 = 33.78(e \cos 23 - 24 \cos -20)$$

Thus $e = 14.9$ knots

which was reasonable enough since Hipper's ships had clearly made a large turn about; the TS recorded their course as '130 to left' at 3.30.

Lion's second recorded rangefinder range was 18,500 yards at 3.46, 1,600 yards higher than the estimated actual value. Even so, the two ranges show a fall of 1,500 yards in 4 minutes, an implied rate of -375 yds/min.

At 3.47½, the rate in use in the TS was -150 yds/min. Their estimate of the enemy speed is not known but they probably assumed that Hipper was still working up to a speed nearer to that of *Lion*; a rate of increase of 1 knot per minute since 3.42 would then have given a speed of almost 21 knots. It is then possible to calculate the probable inclination (ι) in use:

$$-150 = 33.78(21 \cos \iota - 24 \cos -42)$$

Thus: $\iota = 50°$

Since the target bearing was then 42°, this again placed the two forces on almost parallel courses. If, instead, the TS had used the enemy course of SE sent by wireless to Jellicoe, the angle between courses would have been 22½° and the inclination 64½°. Thus the opening rate would have been:

King-Hall was the Control Officer in the After Control of *Southampton*.

[34] Lord Chatfield, *The Navy and Defence* (London, 1942) p.141. Note the similarities in vocabulary with the King-Hall diaries published earlier.

$$\dot{R} = 33.78(21\ \cos 64.5 - 24\ \cos -42) = -297 \text{ yds/min.}$$

i.e. almost double that actually used, though still too small by -274 yds/min.

8. Enemy Course

The enemy course was given in Beatty's signal to Jellicoe as 'S 55° E'. This is a course relative to True North. The magnetic variation in 1916 was 13¼° W,[35] so it was equivalent to (180-55+13¼)=138¼° Magnetic.

SE is 135° magnetic, the 1SG's actual course until *3.44*.

9. *Lion's* Course 3.47-4.00

The courses (magnetic) measured off the BCF's track chart are tabulated below, together with the times and the nearest compass point. The times without brackets appear on the original track chart.[36] Those in brackets are taken from the charts prepared in 1919 by Captain Harper (XXVI-1); despite small angular differences, the courses shown on these later charts differ by less than one compass point: except for the course after 3.52, which was SEbyS rather than SE.[37]

Time	Course angle (magnetic)	Compass point
3.30	91°	E
3.45	108°	ESE
(3.52)	133°	SE
(3.55)	171°	SbyE
4.00	183°	S

In contrast, *Lion's* TS recorded 'Ship A/C to Starboard' at 3.43 (by 1 point), 3.46, 3.49, 3.50½, 3.52½, 3.55 and 4.00.[38] Such continual course alterations compare poorly with 'that steady course which is so important for gunnery'.[39]

[35] 'Remarks on Lord Jellicoe's Comments' in 'Observations on the Narrative of the Battle of Jutland', ADM 116/3188.
[36] 'Track of BCF' (*op. cit.*).
[37] 'Battle of Jutland. Battle Cruiser Action. Second Phase 3.40 to 5 P.M., May 31st 1916', BTY 24/51.
[38] *Lion*, 'Record of Events'.
[39] Chatfield, *Navy and Defence* (*op. cit.*) p.134.

Princess Royal			*Lion*		
Gun range	Target bearing	Time	Time	Target bearing	Rangefinder range
16,000		3.47.35	3.47½	R42	
 14,600	R42	3.48.05 3.48.53	3.48	R45	
14,700		3.49.36	3.49	R53	
 14,200	R78	3.50.05 3.50.15	3.50	R57	15,500
13,200		3.51.15	3.51	R78	
	R89	3.52	3.52	R89	
12,800	R108	3.53 3.53.45	3.53	R108	
			3.54	R107	14,500
 12,800	R115	3.55.05 3.55.15	3.55	R105	
			3.56	R115	15,000
			3.57	R118	
			3.58	R114	
			3.59	R114	
			4.00	R114	
	R130	4.01.20	4.01	R129	16,750
			4.02	R144	
			4.03	R136	
			4.04	R125	
			4.05	R126	
19,100		4.06.50	4.06	R126	
			4.07	R127	
			4.08	R127	(Sight range 21,400)
			4.09	R120	
			4.10	R102	
			4.11	R103	
			4.12	R91	23,000
			4.13	R81	
			4.14	R78	
18,500 18,500		4.15.28 4.15.50	4.15	R80	(Sight range 21,275)
			4.16	R80	21,000
			4.17	R84	
18,500 18,500		4.18.05 4.18.45	4.18	R87	
18,500		4.19.50	4.19	R107	
			4.20	R106	
17,700		4.21.28	4.21	R107	18,800
		etc.	etc.		

10. TARGET BEARINGS AND RANGES

The table on the previous page is based firstly on *Princess Royal's* 'Fore T.S. Record of Action' and lists the 'ranges...on the transmitter when actually firing' and the target bearings from the first salvo until 4.19.50. Notice that the almost complete gap in the record after the breakdown of the Argo Tower; this continued after the hit at about 4.00, following which gas and fumes reached the TS. The table also shows the target bearings from *Lion's* 'Record of Events'; unfortunately, this contains only a few rangefinder ranges and even fewer sight ranges.[40]

Both sets of target bearings suggest that *Lion* and *Princess Royal*, which initially both fired at *Lützow*, followed similar courses until after 4.00. *Lion's* bearings rapidly increase between 4.00 and 4.02 before she swung back onto her new course S; they also confirm her turn to SE at 4.10-13 and to SSE at 4.18/19.

11. *PRINCESS ROYAL*

Rear-Admiral de B. Brock, who commanded the 1BCS in *Princess Royal*, reported that, as the British returned fire:

> The action then became general, the enemy rate of fire being greater than ours due to conditions of light and wind.[41]

The principal effect of wind was to cause smoke interference to those ships firing to leeward. The Admiral may have been referring only to problems from *Princess Royal's* own funnel and cordite smoke but, in a light Westerly breeze, this should not have been serious. *Princess Royal's* record shows that she fired her first five salvoes in only 3 minutes, 40 seconds: but then only two more in the next four minutes. If she was attempting to maintain her distance from the flagship, she would have found it increasingly difficult to keep out of *Lion's* smoke, which appears to be the most likely cause of her reduced firing rate. Her slow firing, even before she was hit, seems to have been noticed by Beatty; at 3.55 or perhaps later, *Lion* made the general signal to 'Increase the rate of fire'.[42]

The sources for the course of *Princess Royal* after 4 o'clock are contradictory. The target bearing for 4.01.20 suggests that she had already turned to course S. In contrast, her officers later recalled:

[40] *Princess Royal*, 'Record of Action'. *Lion*, 'Record of Events'.
[41] 'Notes on Action' with RAC 1BCS to VAC BCF, 3 June 1916 in ADM 137/302.
[42] British 'Record of Messages'.

> Our destroyers (at about 4.2) were between us and the enemy and their smoke together with the smoke from *Lion's* guns which was drifting across our range, was becoming a serious nuisance to our gun control. At 4.6 we altered a point to starboard, to South, to avoid the smoke, and for 10 minutes the range opened until we were firing at ranges between 18,000 and 19,000 yards....At 12 minutes past 4 we had to check fire for a while and we turned back to [SSE], 20 degrees more towards the enemy, to close the range....[43]

Lion's relative position is not mentioned, but, wherever she was, it is difficult to understand how a turn to starboard would have helped in avoiding her smoke. A third source is the small track tracing submitted by Rear-Admiral Brock with his report on the battle.[44] Prior to the 16-point turn at 4.38, this shows only three courses:

77° after 3.29

104° after 3.45 and

158° after 4.10.

These courses must be True courses and, therefore, are equivalent to Magnetic courses of E, ESE and SbyE respectively. However, this is the only indication that *Princess Royal* held to course ESE and turned, but only to SbyE, as late as 4.10.

In the sketched chart (Fig. 6.1), *Princess Royal* and *Queen Mary* are shown turning from SbyE to S just after 4 o'clock. However, it is also possible that this turn, and the next turn from S to SSE, shown at 4.12, could have been later.

12. RANGES, RATES AND COURSES 3.47-4.10

At the start of the action, *Princess Royal*, *Derfflinger's* target, was firing at *Lützow*. Even so, as shown by the table overleaf, until the break in *Princess Royal's* record at 3.55, there is quite good agreement between her ranges and those published by von Hase for *Derfflinger*, even after the German times have been advanced by one minute to synchronise the times when fire was opened. *Derfflinger's* range reached a minimum of 12,350 yards after *3.53*; by *3.54*, it was 12,575 yards. Likewise, *Princess Royal's* range had stopped falling at 3.53 and was still 12,800 yards at 3.55. At 3.56, *Princess Royal* was hit twice. At the same time, von Hase increased the rate to +600 (+660 yds/min.).[45] This is considerably more than would be expected from *Lion's* courses after 3.55 (SbyE) if it is assumed that Hipper

[43] 'Narrative from Officers of H.M.S. "Princess Royal" ' in *Fighting at Jutland*, p.19.
[44] 'PRINCESS ROYAL. Enclosure 13 to BCF 01 of 12 June 1916' in ADM 137/303.
[45] *Princess Royal*, 'Record of Action'. von Hase (*op. cit.*) pp.145, 147, 152 and Sketch I. *Princess Royal's* times are truncated to the nearest minute. *Derfflinger's* ranges in metres are converted at 1 metre=1.0936 yards and rounded to the nearest 25 yards.

Time	*Princess Royal* yards	*Derfflinger*	
		metres	yards
3.47	16,000	15,000	16,400
3.48	14,600		
3.49	14,700		
3.50	14,200		
3.51	13,200	11,900	13,025
3.52		11,500	12,575
3.53	12,800		
3.54		11,500	12,575
3.55	12,800		
3.58		14,800	16,175
3.59		15,200	16,625

held to SSE until 4.00. From 3.56, *Lion's* target bearing was almost steady at R114, so the angle between courses would have been 11¼° and the inclination 102¾°; hence:

$$\dot{R} = 33.78(18 \cos 102.75 - 24 \cos - 114) = 196 \text{ yds/min.}$$

The high rate adopted by von Hase might explain why he did not continue hitting his target after 3.56: except that another hit was made about 4.00, one minute after *Derfflinger's* range had reached 16,625 yards;[46] thus her mean total rate from *3.54* to *3.59* was a very high 809 yds/min. (the difference from the clock rate would be accounted for by UP spotting corrections).

As can be seen from the previous table, *Lion's* rangefinder ranges show a similar upward trend from a minimum at 3.54 of 14,500 yards. Her TS record contains very few gun ranges, though it does give rates and spotting corrections. If, starting with the gun range of 18,500 yards at 3.47½, subsequent gun ranges are calculated, they fall to a minimum of 13,325 at 3.55/6, then increase rapidly to 15,650 at 4.00 and 16,200 at 4.01. Thus they also show a similar though more marked trend than her rangefinder ranges. Beatty's Personal Narrative contains two ranges: 14,300 at 3.56 and 14,600 at 4.02: but the second (recorded when the flagship was being hit repeatedly) is probably wrong.

Thus, apart from this one anomaly, the known ranges for the leading ships show similar trends, falling to a minimum of less than 13,000 yards before increasing again to over 16,500 yards at about 4.00. Unfortunately, the ranges for the ships astern of

[46] *Lion*, 'Record of Events'. Campbell, *Analysis*, p.70. von Hase, p.152.

Derfflinger and *Princess Royal* are more difficult to reconcile. The *Official German Account* contains the following range information.

> ...the "Indefatigable"...had hardly been under fire for 15 minutes from the "von der Tann" when at 5.3 p.m. [4.03] it was observed from that vessel how, after several fierce explosions , amidships and aft, the British battle cruiser disappeared....52, 11-inch and 38, 6-inch shells fired from the "von der Tann" at ranges from 17,000 yards (11-inch) and 15,250 yards (6 inch) down to 13,450 yards had sufficed to secure this result. At the order "change target to the left" the "von der Tann" now transferred her attention to the fifth ship, the "New Zealand", at which 52 rounds were fired from the heavy guns at from [*sic*] 13,450 yards to 17,500 yards range, before the course of the battle necessitated a further change of target [to *Barham* at 4.18].

Although not unambiguous, this passage seems to imply that the range from *von der Tann* did not reach 13,450 until just before the *Indefatigable* blew up: that the range on the sights was not changed when *von der Tann* shifted her fire to *New Zealand*: but that the range then increased. Yet, on the following page, the account continues:

> ...Between 5.4 p.m. and 5.8 p.m., when the range was between 11,500 and 10,400 yards, "Moltke" considered the time ripe for the employment of her torpedo armament....She fired altogether four torpedoes at the third battle cruiser ("Queen Mary")....

In contrast, von Hase's next ranges for *Derfflinger* were 18,000 metres (19,675 yards) at 4.05 and 19,000 metres (20,775 yards) at 4.08![47]

Yet there are similar large differences in ranges between the leading British ships and their consorts astern. The reported courses of the 2BCS would suggest that the actual range fell rapidly until 3.54 but then increased more slowly until 4.00, when *New Zealand* altered to course S. In fact, between *3.51* and *3.54*, her gun range plummeted from 18,100 to 12,500 yards while her rate was increased from -200 to -500 yds/min; thus most of the reduction must have been the result of very large DOWN spotting corrections. Unfortunately, there is then a gap in her rate record, but the gun range continued to fall to a minimum of 10,800 yards at *3.56*. Just before her course alteration at *4.00*, the rate was nil: while the range of her last salvo at *Moltke*, at *4.01*, was 13,800 yards. She then transferred to *von der Tann*, the first salvo being timed at *4.04*, when the rate was 250 yds/min. opening and the range 14,100; by *4.08½*, the range was 16,000.[48] Since she

[47] Admiralty, Naval Staff, *The Battle of Jutland (The German Official Account)*, May 1926 from *Der Krieg zur See, 1914-1918, North Sea* by Captain O Groos, trans. Lieut.-Commander W T Bagot, RN, pp.61-2, AL von Hase, p.152 and Sketch I.
[48] 'Second BCS. Report on Action', 3 June 1916 in ADM 137/302. *New* Zealand, 'Record of Ranges' (*op. cit.*).

made no hits, *New Zealand's* ranges cannot be exact and her minimum was much lower than *von der Tann's*; nevertheless, both ships were using similar ranges just after 4 o'clock.

Tiger was also shooting at *Moltke*. Like *New Zealand*, her initial range was much too high (18,500 yards) and she was forced to make a series of large DOWN spotting corrections; these reduced the gun range to 15,700 yards by 3.54, when both Q and X turrets were put out of action. Thus *Tiger* could no longer fire salvoes; her record lists 20 ranges in the next 9¾ minutes, which suggests that she was firing guns singly or in pairs whenever they were ready (see also XXVI-16). She also continued to be hit, while her gunnery effectiveness was further reduced by smoke interference from British destroyers and from enemy shorts. Her ranges went on falling, to a minimum of 10,500 yards at 4.00½; they then increased to 11,700 at 4.02, 12,200 at 4.03¾ and 14,300 at 4.08.05.[49] Thus the range values are not greatly different from *New Zealand's*, but they tended to lag in time; *Tiger's* minimum range was not reached until four minutes later. In view of her desperate circumstances, *Tiger's* ranges must be suspect but, even so, she probably made the underwater hit on *Moltke* timed by Campbell at '1602 or just afterwards'.[50] Perhaps, therefore, *Moltke's* range of 11,500 yards at 4.04 is not out of the question, though a reduction to 10,400 at 4.08 remains hard to credit.

Do the ranges and rates for the leading ships follow a trend that would be expected from the recorded courses? As described in Chapter 6, at *3.44* Hipper turned his ships together from SE to SSE: which placed them on a line of bearing from the flagship of NW. From 3.49, *Lion* and *Princess Royal* made a series of small turns away which, by 3.55, brought them onto course SbyE; thus the rate of their ranges on *Lützow* must have changed from closing to opening. At *3.53*, Hipper ordered the 1SG to 'Follow in the wake of the leading ship'. Marder, Campbell and Tarrant have assumed that all the ships astern of *Lützow* turned away for a time to a course SE until they reached their flagship's wake, after which they turned back to SSE.[51] While heading SE, the angle between courses was 33¾° and the inclination 80¼° (assuming a target bearing of R114). Hence the rate was:

$$\dot{R} = 33.78(18\ \cos 80.25 - 24\ \cos\ -114) = 433\ \text{yds/min.}^{52}$$

[49] H.M.S. "TIGER", Gunnery Records during Action of 31st May 1916 in ADM 116/1487.
[50] Campbell, *Analysis*, p.85.
[51] *FDSF III* (*op. cit.*) Chart 4. Campbell, *Analysis*, pp.44-5. Tarrant, *German Perspective*, p.82.
[52] At *3.52*, Hipper ordered 'Increase speed' (German 'Summary of Messages') but, since there would have been some loss of speed in the two-point turn, it is permissible to continue using 18 knots for the 1SG.

This is much closer to *Derfflinger's* sustained high rate in use after *3.55*; yet, because she was second in line, the actual rate should have fallen again as soon as she turned back to SSE. However, one of the German Plans in the Beatty Papers (which were lithographed in Britain in 1920, apparently for inclusion in the Harper Record) differs from later charts at the time when Hipper ordered his ships to follow in his wake; it shows the 1SG changing course and formation from a heading SSE on a line of bearing NW to course SE in line.[53] This would have been a much simpler manoeuvre, since it was completed as soon as all ships had turned together to SE.[54] It would also have resulted in ranges and rates conforming better with the records from *Derfflinger* and *Lion*; furthermore von Hase's chart also shows his ship on course SE from *3.54* until *3.59*.[55] It is, therefore, more likely that, at about 3.54, the 1SG turned away; it then follows that Hipper's turn together to SEbyS at *3.59* was a turn towards, not away.[56]

Further astern, the 2BCS kept to course E until *3.54* before turning to SSE; however, *Moltke* and *von der Tann* may already have been turning away. This was probably the moment when the ranges reached their minima, though they were unlikely to have been as low as the 10,800 yards recorded by *New Zealand*. Thus the range from *von der Tann* to *Indefatigable* should have *increased* to 13,450 yards just after 4 o'clock. Unfortunately, the *German Official Account* states that this was the *minimum* value; on the other hand, there are no indications that *von der Tann* made any earlier hits, so perhaps she consistently overestimated the range until her final salvoes at *Indefatigable*. While the actual ranges must remain uncertain, the comparative trends clearly indicate that, in the period leading up to *Indefatigable*'s destruction, the rear ships in the two lines were considerably closer (probably by 2,000 to 2,500 yards) than those ahead.

Tiger's ranges show a similar but delayed trend, though the initial closing rate was not as large. She may have turned to around EbyS when firing began (Fig. XXVI-5), but the repeated hits by *Moltke* until 3.57 suggest that *Tiger* made few significant course

[53] 'German Plan IV. Battle Cruiser Action' and 'German Plan V. Movements of German High Sea Fleet and Approximate Position of British Fleet in the Battle of Jutland 31st May 1916', 'Malby & Sons. Lith.', BTY 24/37-38. The serial number of the latter is 'S507. 39131. SCP. 50/318. 2000. 5. 20.'

[54] However, a more positive order would have been 'Turn together to SE': Grindal.

[55] von Hase, Sketch I.

[56] It is then necessary to disregard the *German Official Account* (*op. cit.*, p.60) which states that: 'Admiral Hipper...bore away two points so as to throw out the enemy's rangefinding'. However, this would have resulted in a course of SE, not the SEbyS ordered explicitly by Hipper.
Gordon, *Rules of the Game*, p.114 also shows the 1SG turning together to SE but their next turn as being in succession.

alterations to throw out the rate. Instead, she appears to have followed a course somewhere between those of *Lion* and *Princess Royal* to starboard and the 2BCS to port. By turning more slowly than the rest of the 1BCS, she would have been able to keep out of their smoke: while, if she did not turn further than to SE, her ranges would have continued to fall until after 4 o'clock. Their general trend, and the close correspondence with *Moltke's* range at 4.04, indicates that, like the 2BCS, *Tiger* was much closer to her opposite number than were *Lion* and *Princess Royal* to theirs.

No specific data have been found for the course of *Queen Mary*. However, she made three hits from 3.56 until after 4 o'clock,[57] so she was able to fire steadily, apparently without serious smoke interference. As soon as *Lion* began turning from ESE towards the South, those astern of her, if they were to avoid smoke interference, needed to veer Eastwards so that the line of bearing from the flagship swung towards the North and even East of North. *Princess Royal* may have followed too closely in *Lion's* wake (see Chapter 6 and XXVI-11), but this would have made it easier for *Queen Mary* to delay her own turns sufficiently to keep the smoke from those ahead on her unengaged side; even so, she may also have been obliged to increase her speed to prevent an increase in her distance from *Princess Royal*. While *Queen Mary* could have kept on the appropriate line of bearing without deviating too far from *Lion's* course, *Tiger* would have had to delay further before making her turns: which would explain why she followed a course well outside that of the rest of the 1BCS.

13. 2BCS: RATES

New Zealand did not report her target bearings. However, if it is assumed that her lines of bearing were roughly parallel to *Lion's*, it is possible to estimate her rates, at least approximately.

At 3.47½, *Lion's* course was ESE and *Lützow's* SSE; thus the angle between courses was 45° converging. Since the target's relative bearing was R42, the inclination was 87° (Fig. XXVI.1). The 2BCS were still on course E, so their target bearing was R(42 – 22.5) = R19.5. Thus the rate was:

$$\dot{R} = 33.78(18 \cos 87 - 26 \cos - 19.5) = -796 \text{ yds/min.}$$

[57] Campbell, *Analysis*, pp.41-2 and 80-3.

After 3.56, the 1SG had turned away to SE and the 1BCS to SbyE i.e. an angle between courses of 33¾° diverging. The target bearing from *Lion* remained fairly steady at about 114°, so the inclination was 80¼°. Since the 2BCS were on course SSE, their target bearing was R102¾ and the rate was:

$$\dot{R} = 33.78(18\ \cos 80.25 - 25\ \cos - 102.75) = +289\ \text{yds/min.}$$

14. *INDEFATIGABLE'S* FINAL POSITION

After *Indefatigable* was first hit, the Navigating Officer of *New Zealand* recalled that:

> We were altering course to port at the time and apparently her steering gear was damaged as she did not follow round in our wake but held on until she was about 500 yards on our starboard quarter.[58]

Andrew Gordon reproduces a photograph of *Indefatigable* already sinking by the stern with the bows to the left.[59] This must be the photograph mentioned by Campbell as having been taken from *New Zealand's* after torpedo control position,[60] and it is consistent with the stricken ship being off her flagship's starboard quarter.

However, no other source mentions a turn to port by *New Zealand*. The 2BCS's track tracing shows two turns to starboard after joining the line, the second following the sinking of *Indefatigable*.[61] *New Zealand's* 'Record of Ranges' indicates that, at *4.00*, she altered course to starboard: though it does not mention any other turns. The first hits on *Indefatigable* must have caused a serious explosion, otherwise, as is clear from the photograph, the after part of the ship would not already have been under water. Such an explosion probably wrecked the steering gear; it may even have blown off the stern.[62] Thus, rather than keeping straight on, she could just as well have veered to starboard. Then, if *New Zealand* was herself turning to starboard, *Indefatigable* would have been on the starboard quarter when the photograph was taken, just before the hits by the second salvo, which blew up her forward magazines.

15. COURSES AND RANGES: SECOND PHASE

After 4 o'clock, Hipper ordered two more turns together of two points, to SEbyE at 4.04 and, at either 4.07 or 4.10, to SbyW.[63] He then increased speed to 23 knots at

[58] 'Narrative of the Navigating Officer of H.M.S. "New Zealand"' in *The Fighting at Jutland*, p.28.
[59] Gordon, *Rules of the Game*, Plate 29.
[60] Campbell, *Analysis*, pp.60-1.
[61] 2BCS Track Tracing (*op. cit.*).
[62] Grindal to author.
[63] The time of the second turn is 4.07 in the German 'Summary of Messages' but 4.10 in the *German Official*

4.12. At 4.18, he ordered his ships to follow in his wake, but the 'German Plan IV' cited in XXVI-12 shows *Lützow* also altering course to South, and this small turn away at 4.18 has been assumed here (see Fig. 6.1). The 1SG then held its course and speed until turning sharply away to SE at 4.27. The earlier changes did little more than prevent the range increasing further. However, at 4.08 or so, the 5BS had closed the range sufficiently to open fire, first on *von der Tann* at 19,000 yards and then, concentrating in pairs, on *Moltke* as well.[64] Beatty quickly responded by turning *Lion* to SE, commencing the turn at about 4.10. The SE course, which gave a rapid (closing) rate of -702 yds/min., was held until 4.19/20, when *Lion* turned away to SSE,[65] thereby reducing the calculated rate to -251 yds/min. (Chapter 2). The BCF Track Chart then shows a starboard turn to S at 4.30, followed by a port turn to SEbyS about four minutes later, prior to the 16-point turn at 4.37 after the sighting of the High Sea Fleet.[66] However, her TS record suggests that she made two starboard turns towards the South at 4.25½ and 4.28 but that she altered back to port at 4.32. Whatever the exact details, all of these course changes appear to have been made without signals.

Before considering the ranges, it is necessary to attempt an identification of the targets fired at from each battlecruiser and of the hits made. *Lion*, *Tiger* and *New Zealand* all continued firing after the sinking of *Indefatigable*. There is no indication in *Lion's* TS record that she changed target, while she remained in view from *Lützow*, though not from some of the ships astern. Yet Campbell attributes two hits on *Lützow* at 4.15 to *Princess Royal*, principally because the latter's range (18,500 yards) was much less than *Lion's* (actually 21,275, not '*c* 23,000', which was a rangefinder range taken at 4.12).[67] However, part if not all of the difference can be explained if *Lion* was still out of line to starboard. And, in any case, it is surely most unlikely that *Princess Royal* was still concentrating on the leading German ship. Admittedly, no change of target is mentioned in her 'Record of Action': but it contains only one bearing and one range between 3.55.15 and 4.15.28, the most likely

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Account (p.63) and on the 'German Plan IV' (*op. cit.*). For this phase, the German times are given unaltered.

[64] Captain A W Craig (*Barham*), 'Report of Action of 31st May 1916' in ADM 137/302 gives the time as 4.11: Beatty's Personal Narrative (*op. cit.*) and VAC BCF to C.-in-C. Grand Fleet, 12 June 1916 in *Beatty Papers I* (*op. cit.*) p.326 as 4.08: and the *German Official Account*, p.64, as 4.06.

[65] The 'Track of BCF' chart shows turns to SE and SSE at 4.12 and 4.20. Beatty's Personal Narrative contains two turns, to port at 4.11 and to SE at 4.12½. *Lion*, 'Record of Events' states 'Ship A/C to Port' at 4.09 and 4.11½ and 'Ship A/C to Starbaord' at 4.18½; the changes in target bearing are consistent with courses of SE and SSE.

[66] 'Track of BCF'. See also Beatty's Personal Narrative for 4.29.

[67] *Lion*, 'Record of Events'. *German Official Account*, p.66. Campbell, *Analysis*, pp.48 and 79.

period for her to have transferred her fire to *Derfflinger*. In fact, von Hase seems to imply that his ship was being straddled before 3.55: but, even if this is incorrect, the officers in *Princess Royal* must have realised, no later than the destruction of *Indefatigable*, that they should engage their opposite number in the German line. Furthermore, Campbell also points out that full details of the hits on *Lützow* are lacking (which is hardly surprising since she sank before reaching harbour);[68] thus the two hits in question may also have been made later, when the ranges in *Lion* and *Princess Royal* were similar (see below).

Lützow began firing again at 4.15 or shortly after,[69] but *Lion* herself escaped further damage until 4.24, when she took two direct hits from *Lützow* and was probably also struck by a ricochet.[70] *Derfflinger* had lost sight of *Lion* and engaged *Queen Mary*, which appeared to be her opposite number.[71] von Hase thought *Queen Mary* was returning his fire, but there is no apparent reason why she should have shifted target; thus Campbell's assumption that she made the hit on *Seydlitz* at 4.17 seems justified. *Seydlitz* did not make the same mistake as *Derfflinger* and the two German ships began the concentration which ended with the explosion of *Queen Mary* at 4.26.[72] She had probably been hit twice (on the port 4-inch after battery and the quarter deck) before, at 4.21, a hit on Q turret put the right gun out of action. There was then a delay until: 'Every shell that the Germans threw seemed to strike the battlecruiser at once'. The first big explosion was caused by a hit on A or B turret but there was probably a second hit on Q turret; this appears to have broken off the left gun and started a cordite fire which resulted in a second magazine explosion.[73] Campbell credits the final three hits to *Derfflinger* and concludes that, before 4.21, *Seydlitz* made four hits, but only two will be counted here.[74] On the other hand, the hit at 4.21 was probably also by *Seydlitz*, not *Derfflinger*. It appears to belong in the first sequence of hits, which ceased while the 1SG were reforming into line; no further hits were made for several minutes, which suggests that *Seydlitz* lost the rate. von Hase did not claim his first straddle until 4.22.40. Also, *Derfflinger's* 'hit-indicators' were still working and proved

[68] *Princess Royal*, 'Record of Action'. von Hase, p.150. Campbell, *ibid.*
[69] *Lion*, 'Record of Events' gives the time as 4.15, von Hase, p.152, as 4.17.
[70] Beatty's Personal Narrative. Campbell, *Analysis*, pp.67-9.
[71] *Lion* would have been hidden from *Derfflinger* whichever course was taken by *Princess Royal* and *Queen Mary* after 4.00 - see XXVI-10 above.
[72] Campbell, *Analysis*, p.80. von Hase, pp.154, 157 and 159.
[73] Williams, 'Loss of *Queen Mary*' (*op. cit.*) pp.122-5 and 132; survivors from *Queen Mary's* X turret described hits before 4.21 on the after 4-inch battery and the quarter deck: while the wreck of *Queen Mary* shows particularly serious damage in the vicinity of Q turret.
[74] Campbell, *Analysis*, pp.62-4.

invaluable during the concentration, whereas *Seydlitz's* had broken down near the start of the battle;[75] thus it is likely that, as soon as *Derfflinger* found the target, and especially after she broke into rapid fire, *Seydlitz* found spotting much more difficult and was unable to find *Queen Mary* again until, perhaps, her final moments.

Between the sinking of *Indefatigable* and *Queen Mary*, *Tiger's* 'Gunnery Records' do not show any change of target from the ' "Seydlitz" cl. 4th ship from the right'. However, her gunnery officer later recollected that:

> About 4.10 I had the greatest difficulty in making sure of my target, as the enemy had a ship ahead of their line, probably a large light cruiser, which was sometimes there and sometimes not, and was making volumes of smoke. For some minutes about now, we counted her as a battle cruiser, and so engaged No. 3 instead of No. 4 of the enemy line.

Presumably as a result of the damage to Q and X turrets, he also appears to have lost confidence in the Director and, in order to line up, at 4.05½ ordered individual firing for 5 minutes. Since *Tiger* had not been fitted with an Evershed installation (Chapter 3), the rangetakers and turret personnel could then determine the target only from its position in the enemy line. The confusion in identifying the target probably also explains why, at 4.11.20, the 'Gunnery Record' contains the remark 'Plotted Rate 850 opening': yet this had no apparent influence on the gun range, which continued to fluctuate, seemingly at random (see the following table of ranges). After *Queen Mary* blew up, *Tiger* switched her fire to the '3rd ship from the left, "Derflinger" [*sic*] class' which presumably means *Seydlitz*: but she was no more successful than she had been against *Moltke*. Throughout the second phase (as in the first) *Moltke* fired at *Tiger*, she made two more direct hits between 4.20 and 4.30, while a third shell which went through *Tiger's* middle funnel at about 4.20 was probably a ricochet.[76]

From *4.03*, *New Zealand* and *von der Tann* exchanged fire until *4.16½*, when *New Zealand* 'Shifted to 4th Ship, 5th ship obscured'. Her record indicates that *Moltke* remained her target for the rest of the engagement: but still she made no hits.[77] At 4.18, *von der Tann* also changed target, to *Barham* leading the 5BS. Despite the extreme opening range, the battleships made their first hit on *von der Tann* almost immediately, at 4.09, while:

> The end ships of the German line were...soon exposed to a regular hail of 15-inch projectiles, and salvoes fired at extremely short intervals, fell all about them.
> ....

[75] von Hase, pp.159-160. *Seydlitz*, 'General Experience', f.272 in 'Jutland. Later Reports', ADM 137/1644.
[76] *Tiger*, 'Gunnery Records' (*op. cit.*). *Tiger's* Gunnery Officer (*op. cit.*) pp.424-5. Campbell, *Analysis*, pp.74-5.
[77] Until about 4.26, *Tiger* was also firing at *Moltke*; the two British ships may again have confused one another's spotting.

> ...By altering their course and speed so as to throw out the enemy's system of fire control, both ships succeeded, for a time at least, in avoiding the enemy salvoes, which possessed almost too little spread.[78]

Even so, *Moltke* was hit twice at 4.17, once at 4.23 and again at 4.24. Meanwhile, *von der Tann*'s steering gear was damaged by the first hit, so either this or her zig-zagging probably resulted in her veering out of line to port so that she and *New Zealand* lost sight of each other. While she was firing at *Barham*, she received a hit at 4.20 which jammed her fore turret training 30° abaft the starboard beam for the rest of the battle.[79] Another hit at 4.23 put the after turret out of action until 8 o'clock. She then turned her midships turrets back to *New Zealand* and, at 4.26, secured a single hit on X barbette (which, fortunately, was not penetrated).

Campbell, without explanation, states that the two hits on *von der Tann* at 4.20 and 4.23 were from 13.5in./1400lb. shell and that they were made by *Tiger*.[80] Yet *Tiger's* Q and X turrets were unable to fire accurately, her control was erratic and, when her fire strayed, it was towards the head, not the rear of the enemy line. While the possibility of two lucky shots cannot be entirely ruled out, it is much more likely that the shell type was misidentified and that this consistent burst of hitting was due to the rapid and accurate salvoes of the 5BS.

After the destruction of *Queen Mary*, *Seydlitz* started firing at *Tiger*.[81] von Hase shifted target to the left and found, to his surprise, that he was again firing at *Princess Royal*; however, most of his salvoes appeared to fall short. Campbell describes three hits on *Princess Royal* between about 4.27 and 4.32 but admits that they were not recorded in detail and that he identified them from photographs.

> One shell struck the muzzle of the right gun of 'Q' turret and burst about 10ft off in the air, causing minor damage to the forecastle deck. The inner tube of the gun was cracked for 2in and the right trunnion bush scored, but the gun continued firing.
> Another shell passed through the second funnel without exploding, and a third...was probably a ricochet...

Since the effect of the first was so slight and it is not clear how its details could have been deduced only from photographs, neither it nor the ricochet have been attributed here to *Derfflinger*. The final hit during the Run to the South, perhaps by *Seydlitz* rather than

[78] *New Zealand*, 'Record of Ranges'. *German Official Account*, pp.64-5.
[79] At the time, *Derfflinger's* target bearing was 52° (von Hase, p.160). Thus the bearing of the jammed turret (120° to starboard) confirms that *von der Tann* was firing at the 5BS.
[80] Campbell, *Analysis*, pp.47-9, 76, 85-94.
[81] *Seydlitz*, ' Experience' (*op. cit.*).

Time	*Derfflinger*	*Lion*	*Princess Royal*	*Tiger*	*New Zealand*[1]
4.00	16,625			10,750:10,500	12,300:13,200
4.01		16,750 R[3]		11,200:11,100:11.000	13,800
4.02				11,700:12,400	
4.03				11,800:12,200	
4.04					14,100[4]
4.05	19,675			12,300:12,700	14,800
4.06			19,100	12,000:12,100	16,000
4.07				13,000:14,100:14,200	16,400
4.08	20,775	21,400		14,300:14,800	16,400
4.09				13,900[5]:16,900	
4.10				17,000:17,900:17,700	17,100
4.11				18,000:17,500	16,900
4.12		23,000 R		17,800:18,000	
4.13				17,300	17,400
4.14				17,400:17,800:17,300	
4.15		21,275	18,500:18,500	17,300	18,100
4.16		21,000 R		17,300:17,300	17,600
4.17				18,100	18,100[6]
4.18			18,500:18,500	17,500	17,600
4.19	17,500		18,500	17,900	18,000
4.20		18,800 R		18,300	17,850:17,450
4.21			17,700	17,500:17,500:16,800	
4.22	15,300:15,200		17,000	16,800	
4.23	14,975			17,400[7]	17,800
4.24	14,775:14,650	16,000 R	16,000:15,900	16,600[8]	17,750
4.25	14,650:14,425:14,325		14,900	15,800:15,800:16,200	17,450
4.26	14,425			16,200	
4.27	13,350[9]	15,500 R		16,000:15,600	16,400
4.28	13,550:13,775			15,500:15,000:14,800	15,100
4.29	15,300			14,000	
4.30	16,000	13,475[10]		13,900:13,700:13,400	14,500:14,800
4.31	16,400		13,000:13,800	12,400:12,300	15,200
4.32	17,175			12,000	
4.33	17,925		15,000	12,000:11,800	
4.34			15,800	11,900	
4.35				13,000	17,350
4.36	18,375			13,600:14,500	18,850
4.37				15,300:15,500	
4.38				16,400	
4.39				17,500	

NOTES

1. *New Zealand's* recorded times are assumed to be 6 minutes fast.
2. All ranges in yards. *Derfflinger's* ranges converted to the nearest 25 yards. Ranges of individual salvoes are listed where more than one fired in a minute;
3. All ranges are gun ranges, except for *Lion's* rangefinder ranges, marked R.

4. Change of target to *von der Tann*.
5. This range must be mistyped, perhaps for 15,900.
6. Change of target to *Moltke*.
7. Possibly two 'salvoes' at 4.23.
8. Change of target to *Seydlitz*. Therefore *Tiger's* times are 2-3 minutes fast at this point..
9. Change of target to *Princess Royal*.
10. This range only is from 'Notes made by Sub Lieut Selby in charge of T.S. of HMS Lion...' in papers of Captain R P Selby RN, IWM 96/20/1.

THE RUN TO THE SOUTH: TABLE OF RANGES 4.00 TO 4.39

Moltke, was received by *Tiger* at about 4.35.[82] Thus, during this second phase, the 1SG made not less than 12 direct hits on Beatty's battlecruisers: which scored 3 in return, or 5 if the last two hits on *von der Tann* are also included. The 5BS made 5 or 7 hits on the 1SG, while *Barham* was hit once by *von der Tann*.

The ranges between the battlecruisers can now be examined in more detail, particularly for indications of the relative courses of the British ships. *von der Tann's* range on *New Zealand* appears to have risen from 13,450 to 17,500 yards before she shifted to *Barham*.[83] Other than this, details of German ranges have been found only in von Hase's memoir; they have been tabulated above, together with the ranges for the four surviving British battlecruisers. von Hase was obliged to order the cease-fire soon after 4.05. He re-opened on *Queen Mary* at 4.17 when 'we were converging on one another fairly rapidly'; the range fell from 17,500 to 15,300 in the 3 minutes after 4.19, though how far this was due to rate rather than spotting is not known. By 4.22 the rate in use was and remained 'E-U-3' i.e. -330 yds/min., quite close to the calculated -250 yds/min. *Derfflinger* spotted straddles by the salvoes timed at 4.22.40 and 4.23.45; she then broke into rapid fire, the next six salvoes being fired from 4.24.20 to 4.26.10 i.e. at an average interval of only 22 seconds.[84]

From 4.00 to 4.08, *Lion's* ranges were similar to *Derfflinger's*, but the next rangefinder range, taken at 4.12 when she was turning SE, was a high 23,000 yards. Her ranges then fell to reach 18,800 yards at 4.20; the actual mean rate was -525 yds/min., a figure not greatly different from what would be expected following her 4-point turn towards the enemy. Unfortunately, her TS once again failed to estimate the enemy course

[82] von Hase, pp.162-4. Campbell, *Analysis*, pp.47,69,71,73 and 76.
[83] *German Official Account*, p.61.
[84] von Hase, pp.152 and 159-163. The tabulated British ranges are from *Lion*, 'Record of Events': *Princess Royal*, 'Record of Action': *Tiger*, 'Gunnery Records': and *New Zealand*, 'Record of Ranges'.

correctly. Probably as a result of the apparent large increase in range from 4.01 to 4.12, the maximum rate in use just before commencing the turn to port towards SE was +500 yds/min: while, when on the new course, a new rate of Nil was adopted at 4.13 and increased, but to only -200 yds/min., at 4.17. After the alteration to SSE (timed in the TS at 4.18½), it was only slightly decreased, to -150 yds/min;[85] since 4.12, every spotting correction had been DOWN, so the fire controllers were evidently beginning to revise their estimated enemy course towards a more converging direction. Yet the spotting corrections continued downwards to reach a total of 5,500 yards DOWN by 4.23. The rate was almost correct at 4.21 (-200 yds/min.) but then increased further to -350 yds/min. at 4.25. If the TS record is correct, only half a minute later, *Lion* made the first of two turns to starboard. By 4.29, the target bearings had increased by 26° such that A and B turrets were no longer bearing; a minute later, a Nil rate was adopted.[86] Assuming that Hipper's turn away at 4.27 had not yet been detected, both bearings and rates indicate a 2-point turn to S. Sub-Lieutenant Selby's notes confirm that, at 4.30, A and B did not bear: but his range of 13,475 yards, is lower than would be expected.[87]

Once again, *Lion's* fire control staff had failed to detect that, on the approach, the range was falling rapidly. Yet, if the apparent range-rate had been measured off the range plot, it would have given a reasonably accurate estimate of the course of the 1SG. Using *Lion's* target bearing at 4.17 of R84:

$$-525 = 33.78(23\ \cos\iota - 24\ \cos\ -84)$$

Therefore $\iota = 124.5°$

Thus the angle between courses works out at 40.5° i.e. the German course could have been estimated as 175.5° magnetic or approximately S, barely one point different from the actual SbyW.[88] At 4.24, hits on the British flagship provided direct evidence that it was well within range; the rangefinder range taken at that time also still showed a strong downward trend, so it probably helped to force the final realisation that the opposing sides were still on converging courses. *Lion* turned away from 4.27 and avoided further hits, but it was already too late for *Queen Mary*.

[85] 'Increase' and "decrease', when applied to rate, refers to changes in the *magnitude* of the rate, whether it is positive or negative.
[86] *Lion*, 'Record of Events'.
[87] Selby, 'Notes' (*op. cit.*).
[88] If an enemy speed of 18 knots had been assumed, the enemy course would have been even closer to SbyW.

Princess Royal's isolated range of 19,100 yards at 4.06.50 is only slightly below the trend for *Derfflinger* and *Lion*. The later recollections of *Princess Royal's* officers stated that their ship turned from S to SSE at 4.12.[89] Then, when her salvo record recommenced, she fired five salvoes at a constant range of 18,500 yards from 4.15.28 and 4.19.50 i.e. her effective rate was nil for almost 4½ minutes. If, as proposed earlier, her target was *Derfflinger*, then her range at 4.19 was 1,000 yards higher than *Derfflinger's* on *Queen Mary*. It is possible that *Princess Royal's* ranging and rate-finding was thrown out at 4.18 when *Derfflinger* turned briefly onto a diverging course of SE or thereabouts, before turning again into line headed South.

By 4.21, *Princess Royal* seems to have realised that her salvoes were going over since her ranges then fell rapidly to 14,900 yards at 4.25, when they had almost converged on the hitting range from *Derfflinger*. However, it is not known whether this reduction was made entirely by DOWN spotting corrections for range or whether she also adopted a closing rate. Particularly if the latter was the case, *Princess Royal* might soon have started to even the score. Instead, there is an unexplained gap in her record from 4.25.20 to 4.31.15, during which, apparently, she fired no salvoes, although, according to her officers, the range fell to 12,000 yards at 4.26 or 27: while they also recalled a turn towards, to SE, at 4.24. The British 'Record of Messages' includes a wireless signal from *Lion*, originated at 4.25, specifically ordering *Princess Royal* to 'Keep clear of smoke': while Beatty's Personal Narrative gives a time of 4.28 for the fire in Q turret caused by the flair-up of smouldering cordite.[90] It appears, therefore, that, as in the first phase, *Princess Royal* got into the smoke from *Lion's* funnels and guns: and that the problem may soon have been made worse by more smoke from the turret fire. When *Princess Royal*'s record resumed, the range was close to that noted in *Lion*, and increasing; both ships were probably again on parallel courses. *Princess Royal*'s ranges continued to be much less than those from *Derfflinger*, which suggests that she underestimated the extent of the turns away by the 1SG from 4.27 onwards.

Despite their ineffective gunnery, the trends in the ranges of Beatty's two rearward ships are so different that they cannot be disregarded. *Tiger's* was most extreme; she remained within less than 14,000 yards from the enemy until 4.07, but her range then

[89] See note XXVI-11 for the passage cited: and the problems of interpreting some of the evidence from *Princess Royal*.
[90] Appendices XXVII and XXVIII.

shot up in three minutes to 17,900 yards. It then fluctuated wildly but no downward trend is apparent until 4.21. Although, after 4 o'clock, she had difficulties in identifying her target, the pattern of ranges suggests that she delayed her turn away for longer than the other British battlecruisers: and that she probably remained somewhat closer to the German line than the ships ahead, until they reduced the range again after 4.12. The destruction of *Queen Mary* was timed in *Tiger's* record at 4.24, when she shifted her fire to *Seydlitz* at a range of 16,600 yards. This must be too high, because she passed through the cloud of the explosion on *Queen Mary's* engaged side;[91] yet her ranges do not fall below *Princess Royal's* until 4.31. Unlike any other ship's, they then continue to fall to a minimum of 11,800 at 4.33.30. While she certainly failed to detect Hipper's large turn away at 4.27, *Tiger* probably followed *Princess Royal* in turning towards the SE, and, again, did not turn back to follow the flagship until later than the remaining battlecruisers. Perhaps the two hits by *Moltke* were made when she was in this exposed position.

During the first phase of the Run to the South, *New Zealand's* ranges did not fall as far as *Tiger's*. After 4.00, they rose more slowly but, by 4.13, had reached similar values. After this, the two rear ships appear to have followed similar courses until the sinking of *Queen Mary*, when *New Zealand* passed the wreck on the non-engaged side.[92] Subsequently, her apparent rate from 4.27 to 4.30 exceeded -600 yds/min., though the range then began to increase again. Thus she probably also turned towards SE for a time, though, having veered to starboard to avoid the stricken *Queen Mary*, she remained furthest from the enemy. At 4.36, her range was actually higher than *Derfflinger's*, so *New Zealand* was apparently more aware than the other British battlecruisers of the extent of Hipper's withdrawal.

16. RATES OF FIRE

Until the hit on Q turret, *Lion* shot steadily, firing 19 salvoes in 12½ minutes i.e. an average interval of 42 seconds. Afterwards, her rate of fire fell off significantly; from 4.01 and 4.33, she fired 30 salvoes, so the mean interval was 66 seconds.[93]

Princess Royal started similarly; her first five salvoes, from 3.47.50 to 3.51.15, had an average interval of 51 seconds. She then only managed two more (at intervals of 2½

[91] Williams, 'Loss of *Queen Mary*', p.129.
[92] *ibid.*
[93] *Lion*, 'Record of Events'.

and 1½ minutes) before her record stops after the hit on the Argo tower. If von Hase was correct in claiming his first straddle at 3.52.20, *Princess Royal's* firing rate slowed as soon as *Derfflinger* found her range: so her gunnery record rather belies the later claims of her officers that her fire was not disrupted by shorts to the same extent as at the Dogger Bank.[94] At some time between 3.55 and 4.00, Beatty made a general signal, by flags and wireless, to 'Increase the rate of fire';[95] this was after the damaging hits on *Princess Royal* and *Tiger*, and it must have been apparent from the flagship that the immediate loss of gunnery superiority was already telling, especially on his second and fourth ships. After *Princess Royal's* record resumes at 4.15.29, it lists 10 salvoes before the gap after 4.25.20 when she got into *Lion's* smoke; 8 of the 10 appear to have been fired in pairs, but the average interval, 66 seconds, was the same as *Lion's* at that time. The interval for her final 4 salvoes, from 4.31.15 to 4.34.15, was just 60 seconds.[96]

Queen Mary fired 17 rounds from each gun of Q turret until, at 4.21, its right gun was put out of action; since *Lion* fired 38 salvoes in the same period it appears that *Queen Mary's* overall firing rate was only slightly more deliberate.[97]

The records from *Lion* and *Princess Royal* definitely give times for each salvo. *Tiger's* record looks similar, but if every time had corresponded to a salvo, she would have fired 85 salvoes up to 4.39. In fact, the right gun of the undamaged A turret fired 27 rounds up to 5.09 (when the run-out gear failed irreparably). As already mentioned, *Tiger's* Q and X turrets were damaged and, on two occasions, she had to resort to individual firing. It seems likely that, after these hits, *Tiger* fired as often as she could, with whatever guns were ready, so that many of the ranges apply to individual shots or salvoes of only two or three guns. However, from 3.51 to 3.54, she fired four salvoes at one minute intervals, so she probably began rather more deliberately than the other 13.5-inch ships.[98]

New Zealand began the action by firing very rapidly at *Moltke*; between 3.51 and 4.01, she recorded 19 gun ranges implying an interval between salvoes of only 33 seconds. Unfortunately, this fusillade had no effect whatsoever. Once she shifted to *von der Tann* and

[94] 'Officers of *Princess Royal*' (*op. cit.*) p.19.
[95] British 'Record of Messages'; Beatty's signal has times of origin and despatch of 3.58 and 3.55!
[96] *Princess Royal*, 'Record of Action'. 'Officers of *Princess Royal*', p.19.
[97] Campbell, *Analysis*, p.62. von Hase, pp.157-8 stated that *Queen Mary* usually fired full broadsides (all eight guns together), though these were almost always over or short. Since it is doubtful that *Queen Mary* was actually firing at him, and firing broadsides would have been very slow at finding a target by bracketing, this claim has been discounted.
[98] *Tiger*, 'Gunnery Records'. Lt.Cmdr. Macnamara, 'Gunnery Report', 4 June 1916 in BTY 6/6.

then back to *Moltke*, her firing rate slowed considerably; between 4.10 and 4.31, she recorded 23 salvoes; an average interval of 57 seconds. However, her salvoes were more irregular than previously; in this second phase *New Zealand* still failed to make a single hit.[99]

Like the British, most German ships fired salvoes with one gun per turret, though *Lützow* fired alternatively from her fore and after turrets.[100] Her first five salvoes took 3 minutes, an average interval of 45 seconds, *Lion* being hit with the fifth. However, her overall rate may have been higher; Campbell states that *Lützow* fired her first 31 salvoes in 19 minutes, an average interval of 38 seconds. In contrast, *von der Tann* seems at first to have fired deliberately - 52 shells, probably between 13 and 17 salvoes,[101] in 14-15 minutes - but she was firing rapidly when *Indefatigable* was sunk by two salvoes falling in quick succession.[102]

von Hase of *Derfflinger* published detailed information on his salvoes at several critical moments of the engagement. At the start, *Derfflinger* fired six salvoes between 3.48 and 3.52.20 (an average interval of 52 secs.); she opened at 16,350 yards but spotted a straddle with the sixth salvo at 12,975 yards after a succession of 'down' spotting corrections totalling at least 1,600 metres (1,750 yards). She then broke into rapid fire, a salvo every 20 seconds or so, until the target was lost. She did not succeed in hitting *Princess Royal* until 3.56, so it is not certain that these hits were made in this first burst.

von Hase also published in a table (overleaf) a detailed record of his ship's part in the destruction of *Queen Mary*. The intervals before the second and third salvoes were 40 and 65 seconds, respectively, each being spotted as straddling short. Since the clock rate was -300 m/min., they must have been made with UP spotting corrections of +100. After three straddles, von Hase ordered rapid fire, the ranges (until 6.25.45) falling at the nominal clock rate. Six salvoes were fired in 1 min. 50 secs. i.e. a mean interval of 22 seconds. The final salvo seems to have been given a +200 spotting correction: as would be expected since the range-rate calculated from the speeds and courses is -230 m/min. In that case, some spotting was evidently possible in rapid fire: and, probably, the last but one salvo (as well as or instead of the last) was spotted as short.

[99] *New Zealand*, 'Record of Ranges'.
[100] P O Dan Sheppard, 'Notes on Jutland' in *Beatty Papers I* (*op. cit.*) p.356.
[101] The higher number would apply if her port wing turret did not bear throughout.
[102] *German Official Account*, p.61. Campbell, *Analysis*, pp.40,43,61 and 364. The rate calculation assumes that *von der Tann's* port wing turret was bearing throughout the first phase.

Time h. m. s.	Training angle	Range in m. .	Deflection	Orders for elevation telegraph, etc.
6 22 -	52°	14,000	left 10	E-U-3!
6 22 40	51°	13,900	„ 16	2 short!
6 23 45	52°	13,700	„ 14	1 short!
6 24 20	52°	13,500	„ 14	Good, Rapid!
6 24 40	52°	13,400	„ 14	
6 25 -	52°	13,400	„ 14	
6 25 20	52°	13,200	„ 14	
6 25 45	52°	13,100	„ 14	
6 26 10	52°	13,200	„ 10	2 short! Heavy explosion on our enemy! Change of target left to the second battle-cruiser from the left!

von Hase also commented:

> It is noticeable in this list that the training angle of the turrets remained practically unchanged and that, therefore, during these vital minutes the ship steered an admirable course.[103]

Derfflinger, like all the ships of the 1SG, was given the opportunity to fire in optimum conditions, thanks to the small and infrequent changes of course clearly signalled by Hipper's flagship.

On changing target to *Princess Royal*, *Derfflinger's* first salvo was spotted as '2 short' but the next as '4 short'. In all, she fired 8 salvoes between 6.27.15 and 6.33.10, of which the 5th and 7th also fell '4 short' i.e. an average interval of 51 seconds.

> The continuing changing training angle recorded in the log show that the ship was steering a very irregular course and was bearing to port. The enemy's bearing was now somewhat more abaft the beam. This put successful rapid shooting out of the question. As a rule there was a full minute between the salvoes. Each time we had to wait for the splashes. When these were observed new orders had generally to be given for deflection, rate and elevation.[104]

[103] *ibid.* p.160.
[104] von Hase, pp.145-8 and 160-4.

APPENDIX XXVII

JUTLAND SIGNALS

THE BATTLE CRUISER FLEET

The following table gives all the signals made between Beatty's heavy ships for the period from just before the first sighting of Hipper's First Scouting Group at 3.15 to the turn Northwards at 4.40. Remarks and some other signals have also been included if they appeared relevant to the gunnery of the battlecruisers of the 1st and 2nd BCS and the battleships of the 5th BS. All times are GMT.

These signals were tabulated in Appendix II of *Battle of Jutland 30th May to 1st June 1916. Official Despatches with Appendices*, Cmd 1068 (London: HMSO, 1920) pp.446-453. The layout and typography of the original tables have been retained but 5-minute dividing-lines have been added; some redundant punctuation has been omitted.

Time of Despatch	From	To	System	Message	Time of Origin
3.12	SO BCF	General	Flags	Admiral intends to proceed at 23 knots.	
3.13	SO BCF	General	Flags	Alter course leading ships together the rest in succession NE.	
3.14	*SO 5th BS*	*5th BS*	Flags	*Alter course in succession to E, speed 22 knots*	
3.15	New Zealand	-	-	Remarks: Sighted five Enemy ships on starboard bow.	
3.20	SO BCF	General	Flags	Admiral intends to proceed at 24 knots	
3.21	*SO 5th BS*	*5th BS*	Flags	*Alter course in succession to NE, speed 23 knots.*	
3.23	*P. Royal*	*SO BCF*	Flags	*Attention is called to E by N.*	
3.25	Lion	-	-	Remarks: Enemy in sight on starboard bow.	

Time of Despatch	From	To	System	Message	Time of Origin
3.27	SO BCF	General	Flags	Assume complete readiness for action in every respect.	
3.30	*SO 5th BS*	*5th BS*	Flags	*Assume complete readiness for action in every respect.*	
3.30	SO BCF	General	Flags	Alter course leading ships together, the rest in succession to E, speed 25 knots.	
3.32	SO BCF	General	Flags	Alter course leading ships together, the rest in succession to East.	
3.34	SO BCF	2nd BCS	Flags	Prolong the line by taking station astern.	
3.35	SO BCF	SO 5th BS	S.L.	Speed 25 knot. Assume complete readiness for action. Alter course leading ships together the rest in succession to E. Enemy in sight.	
3.35	*SO 5th BS*	*5th BS*	Flags	*Alter succession in course [sic] to E, speed 24 knots.*	
3.35	SO BCF	General	Flags	Admiral intends to proceed at 24 knots.	
3.35	SO BCF	General	Flags	Enemy in sight bearing E by N.	
3.36	*SO 2nd BCS*	*2nd BCS*	Flags	*Alter course in succession 16 points to starboard.*	
3.40	**SO BCF**	**C.-in-C.**	W/T	**Urgent. Enemy Battle Cruisers, five in number, bearing NE, Destroyers, large number, bearing NE, course unknown. Position of reporting ship Lat. 56° 53' N, Long. 5° 28' E.**	**1535**
3.40	*SO 5th BS*	*5th BS*	Flags	*Admiral intends to proceed at 24½ knots.*	
3.45	*SO BCF*	*Battle Cruisers*	Flags	*Form on a line of bearing NW.*	
3.45	**SO BCF**	**C.-in-C.**	W/T	**Urgent. Course of Enemy S 55° E. My position Lat. 56° 53' N, Long. 5° 53' E.**	**1545**
3.45	SO BCF	General	Flags	Alter course together to ESE.	
3.46	*SO BCF*	*Battle Cruisers*	Flags	*Lion and Princess Royal concentrate on Enemy's leading ship.*	
3.47	Lion	-	-	Remarks: Enemy opened fire.	
3.47	*SO 5th BS*	*5th BS*	Flags	*Enemy in sight bearing E.*	
3.47	SO BCF	General	Flags	Open fire and engage enemy.	
3.47	Lion	-	-	Remarks: Lion opened fire.	
3.50	Lion	-	-	Remarks: Lion being frequently hit by Enemy. Turret wrecked at 4 p.m.	
3.55	**SO BCF**	**C.-in-C.**	W/T	**Urgent. Am engaging enemy. My position Lat. 56° 53' N, Long. 5° 31' E.**	**1550**
3.55	SO BCF	General	Flags and W/T	Increase the rate of fire.	1558

Time of Despatch	From	To	Sys-tem	Message	Time of Origin
4.0	*SO 5th BS*	*5th BS*	Flags	*Open fire and engage the Enemy.*	
4.1	Lion	-	-	Remarks: Indefatigable blew up.	
4.10	*SO BCF*	*Princess Royal*	W/T	*Main W/T out of action.*	*1605*
4.11	Lion	-	-	Remarks: Nottingham reports Submarine on starboard side.	
4.11	SO BCF	Destroyers	S.L.	Clear range.	
4.18	*SO 5th BS*	*5th BS*	Flags	*Ships in column to be three cables apart. Speed 24 knots.*	
4.20	Lion	-	-	Remarks: Queen Mary blew up.	
4.26	*SO BCF*	*Princess Royal*	W/T	*Keep clear of smoke.*	*1,625*
4.30	*SO 5th BS*	*5th BS*	Flags	*Subdivisions separately alter course in succession two points away from the Enemy preserving their formation.*	
4.30	*SO 5th BS*	*5th BS*	Flags	*Alter course together 4 points to port.*	
4.30	*SO 5th BS*	*5th BS*	Flags	*Negative alter course together 4 points to port*	
4.33	Southampton	SO BCF	S.L.	Battleships SE.	
4.38	**Southampton**	**C.-in-C. SO BCF**	W/T	**Urgent. Priority. Have sighted Enemy battlefleet bearing approximately SE, course of enemy N. My position Lat. 56° 34' N, Long. 6° 20' E.**	**1638**
4.40	*SO 5th BS*	*5th BS*	Flags	*Subdivisions separately alter course in succession two points away from the Enemy preserving their formation.*	
4.40	*SO 5th BS*	*5th BS*	Flags	*Concentrate in pairs from the rear.*	
4.40	SO BCF	General	Flags	Alter course in succession 16 points to starboard.	

GERMAN SIGNALS

The table below are the more important signals made to and from (mainly from) Hipper's flagship, the *Lützow*, from just before the sighting of the BCF until the 1st Scouting Group (1SG) turned North.

The entries are taken from Appendix 10 of V E Tarrant, *Jutland. The German Perspective* (London: Arms and Armour Press, 1997) pp 276-9. This, in turn, was based on the Admiralty Intelligence Division Compilation and Translation in the Admiralty Library. The text has been reformatted into a similar tabular form to that used for the British signals. Times have been converted to GMT by advancing them by one hour.

All signals from *Lützow* to the 1SG without a time of origin were made visually. The remainder are assumed to be by wireless.

From	To	Time of Origin	Received	Message
Lützow	1SG		2.59	Course NNW.
Lützow	1SG		3.00	Speed, 23 knots.
Lützow	1SG		3.15	Course NW.
Lützow	C.-in-C.	1520 [sic]	3.13	Only four enemy cruisers in sight. Position of 1SG 022ε. Course, NNW.
Lützow	1SG		3.24	Speed, 18 knots.
Lützow	1SG		3.26	Course, NWbyN.
Lützow	General	1529	3.30	2SG close on 1SG. Large enemy ships in sight in 151γ.
Lützow	1SG		3.29	Distribution of fire from the right.
Lützow	1SG		3.32	Speed, 18 knots.
Lützow	1SG		3.35	Course, SE.
Lützow	General	1529	3.35	Enemy battle fleet in sight in 151γ. Enemy battle fleet consists of six ships, steering N.
Lützow	1SG		3.30 [sic]	Distribution of fire from the left.
Lützow	1SG		3.40	Speed, 18 knots.
Lützow	1SG		3.42	Ships to be 500 metres apart.
Lützow	1SG		3.45	Turn together to SSE.
Lützow	1SG		3.48	Open fire.
Lützow	General	1532	3.49	1SG. Position 004ε. SE. Speed, 21 knots.
Lützow	1SG		3.53	Increase speed.
Lützow	1SG		3.54	Follow in the wake of the leading ship.
Lützow	General	1546	3.54	6 enemy battle cruisers, also smaller vessels in 151γ, steering SE. 1SG in 004ε. Course SSE; 18 knots. Am in action with 6 battle cruisers. Request position of own battle fleet.—A.C. Scouting Forces.
Lützow	1SG		4.00	Turn together to SEbyS.
Lützow	1SG		4.04	Turn together to SbyE.
C.-in-C.	Fleet and A.C. Scouting Forces	1609 [sic]	4.05	Own battle fleet, 4 p.m. Position 043ε Centre. Course NW. Speed, 15 knots.
Lützow	1SG		4.07	Turn together to SbyW.
Lützow	1SG		4.12	Speed, 23 knots.
Lützow	1SG		4.18	Follow in the wake of the leading ship.
Lützow	1SG		4.25	Reduce speed.
Lützow	1SG		4.27	Turn together to SE.
C.-in-C.	*Lützow*	1731 [sic]	4.30	To A.C. Scouting Forces: Own battle fleet 035ε, steering N. Speed, 15 knots.
Lützow	1SG		4.34	Turn together to ESE.
Lützow	1SG		4.36	Turn together to E.
Lützow	1SG		4.38	Turn together to SSE.
Lützow	1SG		4.41	Turn together to SSW.
Lützow	1SG		4.44	1SG: Open fire at battleships.

From	To	Time of Origin	Received	Message
Lützow	1SG		4.46	Turn together to SE.
Lützow	1SG		4.49	Follow in the wake of leading ship.
Lützow	1SG		4.51	Course, N.

APPENDIX XXVIII

BEATTY'S PERSONAL NARRATIVE

Beatty's own tabular narrative of events can be found at the National Maritime Museum in BTY 6/3, 'Action with the German High Sea Fleet 31st May - 1st June 1916. VABCFs Personal Records'. The following is a transcription of the record for the Run to the South. The first four columns appear in the narrative itself. The right-hand column of explanatory 'Comments' and the 5-minute dividing-lines have been added by the present author.

The interpretations of signals are based on:

i. *The Flotilla Signal Book for the use of His Majesty's Fleet, 1908*, NMM.

ii. Captain P J Russell, *Sea Signalling Simplified* (London: 1976).

BATTLE OF 31st MAY. NARRATIVE OF EVENTS

Time	From	To	Note	Comments
3.28	VA	Gen	G 25. Course E.	Guide of Fleet to make 25 knots.
3.29	VA	2BCS	Prolong line ahead.	
3.30			G.25 down	25 knot signal made executive.
3.31			Range of enemy 23000 yds.	
3.32			2nd BCS take station astern, CHAMPION and destroyers ahead.	Countermands 3.29 signal which cannot have been made executive.
3.35			Two enemy quite distinct to me.	
3.37			H.13 pdt.	13th Flotilla to attack as previously arranged.
3.40			I can see 4 enemy port bow.	
3.42	VA	Champ.	Take station 2 points on Stbd bow.	
3.43	VA	BCs	Form on line of bearing NW.	
3.44			I can see 5 enemy BCs.	
3.45			O pdt. H down	Signal 'Form compass line of bearing NW' to be hauled down i.e. made executive.

Time	From	To	Note	Comments
3.46			P1. H tackline QZ	P1 - leading pair of ships to concentrate. H tackline QZ - destroyers to proceed at utmost speed [?]
3.47			Blue pdt. CH. 5 flag.	Blue pendant, CH - alter course together to ESE. 5 flag - open fire.
3.47			Enemy opened fire.	
3.47½			Lion opened fire.	
3.49			Enemy salvo over.	*Lützow's* opening range too high.
3.50			ditto.	
3.50½			LION hit by enemy.	
3.52			LION hit by enemy centre funnel	
3.54			Enemy salvo short.	
3.54½			ditto.	
3.56			Range 14300.	
3.57			Enemy salvo 2 short & 2 over	
3.57½			Enemy straddled us again.	
3.58			(Flag Capt.) Tell Fore Top we are short.	
3.59			Enemy straddled us.	*Lützow* keeping *Lion's* range with a proportion of shots falling short.
3.59½			Enemy straddled us again. ? one hit.	
4.0			Q turret wrecked.	
~~4.0~~	~~VA~~	~~Destr-oyers~~	~~Attack with torpedoes.~~	This entry deleted
4.1			Enemy hit us	
4.1½			Again (I think Indefatigable blew up about now)	
4.2			Enemy straddled us. Range 14600 A/c one point to Stbd.	
4.3			Enemy hit us.	
4.5			Destroyers smoke (own) obscuring target.	
4.8			5th B.S. opened fire.	
4.9			Torpedo reported to have passed us from Std. to Pt. Range 21100.	
			4.10 Landrail sighted periscope Port Q. Torpedo passed between Tiger and NZ.	Added in Beatty's red ink.
4.11			A C to Port. NOTTINGHAM reports submarine.	
4.12			Enemy salvo short. Our course SSE.	
4.12½			A/C to SE.	

Time	From	To	Note	Comments
4.17			Enemy salvo over.	
4.18			Third enemy ship on fire?	Probably the fire in *Seydlitz's* turret.
4.19			Enemy over	
4.19½			Enemy salvo ahead.	Deflection wrong.
4.20			A/C to SSE.	
4.24			LION hit twice by enemy.	
4.24½			Again.	
4.26			Explosion in Queen Mary.	
4.28			Fire around Q turret of LION.	Cordite reignited.
4.29			Port 5	5° of port helm to turn to starboard.
4.32			Enemy salvoes short.	
4.33			A/C to SSE.	
4.34			Enemy salvo over.	
4.38			Enemy Battle Fleet ahead.	
4.43			Course North. I can see enemy Battle Fleet. Destroyers recall.	
....			....	

APPENDIX XXIX

THE THIRD BATTLE CRUISER SQUADRON

INVINCIBLE

Excerpts from Commander H E Dannreuther, Gunnery Officer of *Invincible*, to Captain F W Kennedy, *Indomitable*, 2 June 1916 in ADM 137/302.

> "INVINCIBLE"...came into action at about 6.15.p.m. with the leading enemy battle cruiser which was thought to be the "DERFFLINGER". Fire was opened at the enemy at about 8000 yards and several hits were observed.
> A few minutes before the INVINCIBLE" blew up Admiral Hood hailed the Control Officer in the Control Top from the fore bridge "Your firing is very good", "keep at it as quickly as you can, every shot is telling"....
> The Ship had been hit several times by heavy shell but no appreciable damage had been done when at 6.34 p.m. a heavy shell struck "Q" turret and bursting inside blew the roof off. This was observed from the Control Top. Almost immediately following there was tremendous explosion amidships indicating that "Q" magazine had blown up. The ship broke in half and sank in 10 or 15 seconds.

Commander Dannreuther to the Post War Questions Committee, ADM 116/2060.

> At Jutland, only instrument used at all was fore-top rangefinder; that gave a range on opening fire, and we then went on as best we could, all other means of getting ranges impossible, owing to smoke, spray, shell bursting short and other interference.
> ....
> Q. What is your own theory as to reason for "Invincible" blowing up.
> A. Shell was seen by next astern to hit Q-turret and 2 seconds after, roof was seen to blow off, shell burst inside and ship went up as cordite got ignited.
> Q. Did you have your magazine doors open?
> A. Yes, we could not help it; huge great things; cordite in trunk was absolutely exposed.

INFLEXIBLE

Excerpt from Captain Heaton Ellis, *Inflexible*, to VAC BCF, 10 June 1916 in BTY 6/6.

> 6.16-6.35 Object - Green 80, battleship (believed to be "KONIG" class). Range 8000 yards. One enemy ship only could be seen at first though flashes from others astern were visible. There was practically no rate, except towards the end of this period when the enemy turned away and the Squadron turned twice towards them. Small corrections were supplied to begin with as the target was hit with first salvo: afterwards it was only possible to judge by shorts as the enemy was apparently being engaged by whole Squadron...
>
> 6.28. At about this time, object was shifted to the next astern as the latter was becoming visible and was apparently firing from 5 turrets and appeared herself to be unfired at.
>
> 6.30 "INVINCIBLE" was sunk. Shortly after the enemy was lost in the mist.

Apart from the turret between the funnels, the silhouettes of the *König* and *Derfflinger* classes were similar. In the five-turret *Seydlitz*, there was a much bigger gap between the second funnel and the main mast.[1] Thus *Inflexible*, the second in the 3BCS line, fired first at *Derfflinger* and then shifted to *Seydlitz*. *Seydlitz* was hit once, at about 6.34.[2]

INDOMITABLE

Excerpts from the report of the Gunnery Lieutenant-Commander with Captain M H Hodges, *Indomitable* to RAC, 2nd BCS, 10 June 1916 in BTY 6/6.

> 6.25 p.m. "A", "Q" and "X" now opened fire on the centre enemy Battle Cruiser which was on our beam (90 Green) and appeared to be firing at us; I considered that the third enemy Battle Cruiser was engaged by "LION".
> The range we opened fire at was 9,500, deflection -nil & rate -100; the former was by Fore Top Range Finder, the two latter from the Dumaresq set by estimation. We soon established the range and I saw several "Straddles" and bursts.
> Another ship was firing at our target....
>
> 6.30 p.m. The Germans had found our range & appeared to be straddling us....
>
> 6.34 p.m. The "Invincible" blew up.
>
> 6.42 p.m. We "Checked Fire" as the First Battle Cruiser Squadron was coming up on our starboard side & we were ordered to form astern.
> ....
> ...Range finding was most difficult. No plot was obtained.

The wording suggests that *Indomitable* could see only three of Hipper's five ships. From 6.17 to 6.27, *Tiger* was firing at the '3rd ship from left' (*Seydlitz*): while *Princess Royal* fired

1. Erich Gröner, revd. Dieter Jung and Martin Maass, *German Warships 1815-1945, Volume I* (London, 1990) pp.27 and 55-6.

2. N J M Campbell, *Jutland. An analysis of the fighting* (London, 1986) p.187 attributes this hit to *Indomitable*.

only one salvo between 6.17 and 6.29. Most probably, *Indomitable's* target was *Derfflinger*. In that case, the third visible enemy battlecruiser was *Seydlitz*, engaged not by *Lion* but by *Tiger*. Then the other ship firing at *Indomitable's* target was, as already deduced, *Inflexible* (before she shifted to *Seydlitz*). *Derfflinger* received three 12-inch hits at this time, but no 13.5-inch;[3] thus *Princess Royal's* single salvo probably did not fall close and went unnoticed.

If these conclusions are correct, then *Invincible* alone was responsible for the eight damaging hits on *Lützow*.[4]

DERFFLINGER

Georg von Hase (trans. A Chambers and F A Holt), *Kiel and Jutland* (London: Skeffington & Son, 1921) p.182 believed that more than one ship was firing at *Derfflinger*.

> ...we were being subjected to a heavy, accurate and rapid fire from several ships at the same time. It was clear that the enemy could now see us much better than we could see them. This will be difficult to understand for anyone who does not know the sea, but it is a fact that in this sort of weather the differences in visibility are very great in different directions. A ship clear of mist is much more clearly visible from a ship actually in the mist than vice versa. In determining visibility an important part is played by the position of the sun. In misty weather the ships with their shady side towards the enemy are much easier to see than those lit by the sun.

[3] *ibid.* p.185.
[4] *ibid.* p.183 assumes that some of these hits were made by *Inflexible*.

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1904/				
9,461	25 Apr	24 Feb 05	A T Dawson J Horne	Vickers Clock.
11,535	19 May	18 Feb 05	W H Lock A H Pollen	Simultaneous transmission system.
17,719	15 Aug	7 Jun 05	J S Dumaresq	Dumaresq Rate Finder.
23,872	4 Nov	3 Aug 05	W H Lock A H Pollen	Bearing observation, transmission and course plotter.
1906/				
595	9 Jan			Virtual-course range and bearing keeper (abandoned: *IDNS*, pp.82 and 104).
4,422	23 Feb	3 Aug 06	A Barr W Stroud	Transmitters and Receivers
13,082	6 Jun	27 Dec 06	A H Pollen H Isherwood	Tactical machine (the 'crab' machine).
14,305	22 Jun	22 Jan 07	„	Tactical machine.
23,846	26 Oct	25 May 07	„	Dual gyro directional reference.

Year & Patent	Applied for	Complete Spec.	Patentees	Subject (not title)
1908/				
2,497	4 Feb	4 Aug 08	„	Range clock (on virtual-course principles).
14,415	7 Jul	7 Jul 08	„	Transmitters and clutch-operated rotary receivers.
16,463	4 Aug		F C Dreyer J T Dreyer	Rangefinder mounting, three operators (secret).
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25,654	27 Nov	27 May 09	H Isherwood	Multi-speed drive (interchangeable discs).
1909/				
5,031	2 Mar	13 Sep 09	A H Pollen H Isherwood	Manual course plotter.
9,223	19 Apr	19 Oct 09	„	Clock-regulated constant-speed electric motor.
11,795	19 May	7 May 09	„	Air-driven, continuously-running gyro.
21,733			F C Dreyer	Tactical plotter? (secret).
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22,140	23 Sep	12 Apr 11	F C Dreyer	Fire Control Table (secret).
1911/				
360	5 Jan	28 Jun 11	A H Pollen H Isherwood	Argo Clock Mark I (complete the same as provisional).
362	5 Jan	11 Jul 11	„	Range-adjustment and training of rangefinder with variable-speed drives.
7,382				Solving linkage (not reassigned to Pollen).
7,383	24 Mar	25 Sep 11	„	Step by step transmission gear.
19,627	4 Sep	4 Apr 12	„	Argo Clock Mark II (provisional) and Mark III (complete). This secret patent was never reassigned to Pollen and hence never printed as a British patent.
1912/				
17,441	4 Apr	4 Apr 12	„	Disc-ball-rollers variable-speed drive.
21,480	20 Sep		F C Dreyer	Gyro compass relay to Dumaresq. Rate transfer by step-by-step receiver motors (secret).
23,349	12 Oct	11 Apr 13	A H Pollen H Isherwood	True course plotter.
23,351	12 Oct	13 May 13	„	Range and bearing rate plotter.
25,768	9 Nov	8 May 13	A H Pollen G B Riley	Averaging range receiver.

Year & Patent	Applied for	Complete Spec.	Patentees	Subject (not title)
1912/				
30,090	31 Dec	18 Jul 13	A H Pollen H D Taylor	Rangefinder with enhanced image brightness.
1913/				
11,009	9 May	8 Dec 13	A H Pollen H Isherwood	Argo Clock Mark V dumaresq.
16,373	16 Jul	16 Jan 14	„	Argo Clock Mark V change-of bearing mechanism.

Notes

1. Other patents by Pollen and Isherwood, though not cited in the text, are:
   1907/4,311 and 11,040
   1908/1,367 and 1,368
   1909/12,707
   1911/7,381 and 14,302
   1912/1,562 and 23,352
   1913/4,164 and 14,521
   1914/24,830.

2. Copies of Dreyer's secret patents, other than 1910/22,140, have not been found.

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1,062,500 A H Pollen and H Isherwood, *Ball-and-disc Variable-speed Mechanism*, 20 May 1913, filed (Ser. No. 729,643) 5 November 1912.

1,123,795 A H Pollen and H Isherwood, *Means and Apparatus for Charting the Position of Ships at Sea*, 5 January 1915, filed (Ser. No. 788,261) 5 September 1913.

1,162,510 A H Pollen and H Isherwood, *Range-clock*, 30 November 1915, filed (Ser.No. 788,266) 5 September 1913. [Argo Clock Mark III]

1,162,511 A H Pollen and H Isherwood, *Range-clock*, 30 November 1915, filed (Ser.No. 831,702) 14 April 1914. [Argo Clock Mark V dumaresq]

1,232,968 A H Pollen and H Isherwood, *Apparatus for Determining Sighting Data for Naval Guns*, 10 July 1917, filed (Ser. No. 850,319) 11 July 1914. [Argo Clock Mark V change-of-bearing mechanism]

1,317,915 Hannibal C Ford, *Mechanical Movement*, 7 October 1919, filed (Ser. No. 83,749) 13 March 1916.

1,370,204 Hannibal C Ford, *Range Keeper*, 1 March 1921, filed (Ser. No. 205,357) 4 December 1917.

1,450,585 Hannibal C Ford, *Range and Bearing Keeper*, 3 April 1923, filed (Ser. No. 240,883) 19 June 1918.

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